THE MANAGEMENT OF DYNAMOS

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A Handybook of Theory and Practice

FOR THE USE OF

MECHANICS, ENGINEERS, STUDENTS, AND OTHERS IN CHARGE OF DYNAMOS

BY

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ELECTRICAL ENGINEER

With Numerous Illustrations

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PREFACE.

In preparing this volume, it has been the aim of the Author to keep in view the requirements of Mechanics, Engineers, Students, and others, who, having (or expecting to have) the charge of Dynamos, desire to make themselves sufficiently acquainted with their construction, as well as with those scientific principles of which some knowledge is required for the intelligent management of the dynamo.

The work—which has been arranged in what appeared to the Author its natural order—may be regarded as consisting of three parts, although these "parts" overlap each other. In the First of such parts, comprising Chapters I. to IV., the elementary theory of the dynamo, and the electrical and magnetic laws and truths affecting its construction, are considered briefly, and only in so far as they relate to the management of the dynamo: in the Second part, which includes Chapters IV. to VIII., the construction and action of the different classes of dynamos in common use are described: while the Third part—Chapters VIII. to XII.—relates to such matters as affect the practical management and working of dynamos.

For the full theory of the dynamo the reader is referred to the works of Thompson, Kapp, Fleming, and others.

HEATON, NEWCASTLE-ON-TYNE,
June 1895.

CONTENTS.

THE MANAGEMENT OF DYNAMOS.

CHAPTER I.

ELECTRICAL UNITS.

Electro-Motive Force. — Electro-motive force, also termed electric pressure, voltage, &c., occupies the same place in relation to electricity as pressure to steam or water. Water only flows from one place to another when there is a difference of level or pressure of water between the two places, and the flow of water takes place from the place of higher level or pressure to the place of lower level or pressure. In exactly the same way electricity only flows from one place or point to another when there is a difference of electrical level or pressure, or an *electro-motive force*, between the two places, and the flow of electricity takes place in a direction from the higher to the lower pressure. The point where the pressure is higher is said to have a *positive potential*, and is usually denoted by the sign + (plus) or P; and the point where the pressure is lower is said to have a *negative potential* and is denoted by the sign – (minus) or N. Electrical pressure, or electro-motive force, may be produced by chemical action, as in the electric battery; by the motion of electrical conductors in a magnetic field, as in the dynamo; and by numerous other means.

Fall of Pressure.—Pressure in electricity and pressure in steam or water also possess other points in analogy; *e.g.*, in flowing from one point to another they both become less as they recede from the source, or point of higher pressure, in proportion to the resistance met with, or in doing work which may be expressed as resistance. When a current of water flows through a long length of pipe a certain amount of pressure is always lost in overcoming the resistance which the pipe offers to the flow of water. Similarly, when an electric current flows through a long length of conducting cable a certain amount of pressure is always absorbed in overcoming the resistance which the cable offers to the electric flow. If the cable has a uniform resistance throughout the whole of its length, the pressure will fall uniformly; if, however, part of the cable has a greater resistance than another, as may be the case if different portions are made of different materials, or one portion has a greater cross sectional area than another, then the pressure falls most rapidly along the part offering the greatest resistance. The fall of pressure in a "circuit" composed of different resistances is graphically represented in Fig. 1. The portions of the circuit A A A A are composed of copper conducting cable, B is a coil of german silver wire, and C is an incandescent lamp. The current flows in a direction from the positive to the negative, and, as indicated by the dotted and sloping lines, the pres-

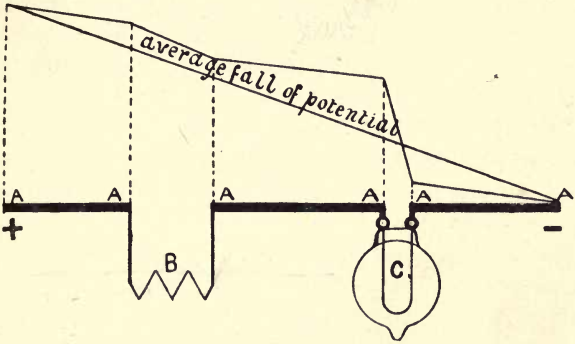

FIG. 1.

sure falls all along the circuit in proportion to the resistance. As will be seen only a slight fall takes place in the copper portions of the circuit, for these being composed of good conducting material offer only a small resistance, as compared with the rest of the circuit; a rather greater fall takes place in the german silver coil, whilst the greatest fall occurs in the incandescent lamp, since this latter has the greatest resistance.

Unit of Electro-Motive Force. — The unit of electro-motive force or electrical pressure is called the *Volt*, and the instrument used in practice for measuring electrical pressure is called a Voltmeter. It is possible by means of suitable machinery to produce almost any desired pressure from a fraction of a volt upwards. The pressures most commonly used in commercial practice vary from .5 volt up to 300 volts in the low tension system, and from

300 volts up to 10,000 volts in the high tension system.

Current. — As electro-motive force or electrical pressure is analagous to *pressure* in steam or water, so is electrical current analagous to the *volume* or *quantity* of water flowing through or discharging from a pipe or other conduit.

Unit of Electrical Current.—The unit of electrical current is called the *Ampere*, and the instrument used commercially for measuring current strength is the *Ammeter*. Although not strictly correct, we may compare a current of electricity of so many amperes to a current of water flowing at the rate of so many gallons per minute. The ampere is therefore the name given to a particular strength of electric flow, which may be measured in various ways by the effects which it produces, as thermal, magnetic, chemical, &c.

Resistance.—A current of electricity always flows in a conducting circuit when its ends are kept at different potentials, in the same way that a current of water always flows in a pipe when a certain pressure of water is supplied. The same electrical pressure does not, however, always produce a current of electricity of the same strength, nor does a certain pressure of water always produce a current of water of the same volume or quantity. In both cases the strength or volume of the currents is dependent not only upon the pressures applied, but also upon the *resistance* which the conducting circuit offers to the flow in the case of electricity, and on the friction (which may be expressed as resistance) which the pipe offers to the flow in the case of water.

Conductors and Non-Conductors.—No known substance is an absolute non-conductor of electricity, in the same way that no known substance is an absolute non-conductor of heat. Some substances, however, such as wood, glass, slate, ebonite, india-rubber, &c., offer a very considerable resistance to the electric flow, and are therefore called "*non-conductors*" or *insulators*. Other substances, such as the metals, carbon, water, &c., offer only a very slight resistance to the electric flow, and are therefore called *conductors*.

Laws of Electrical Resistance.—The laws of electrical resistance are very simple, and may be briefly stated as follows :—"The resistance of a conductor is proportional to the length of the conductor, and inversely proportional to the cross section of the conductor, and also depends upon the material of which the conductor is made, *i.e.*, upon its specific resistance."

Unit of Electrical Resistance.—The unit of electrical resistance is called the *Ohm*, and the ohm is defined to be equal to the resistance of 106 centimetres of mercury, 1 sq. millimetre section at zero centigrade. One yard of No. 40 B.W.G. copper wire has a resistance of approximately one ohm.

Ohm's Law.—It has been mentioned above that the strength of an electric current is dependent upon the difference of potential between the ends of the conducting circuit, and upon the resistance of the circuit. This relation may be shown exactly by the aid of *Ohm's Law*, which states that "the strength of the current varies directly as the electro-motive force or pressure, and inversely as the resistance." This law may be expressed algebraically by the following simple equation :—

$$C=\frac{E}{R.}(1)$$

where C = Current in amperes

E = E.M.F. or pressure in volts

R = Resistance in ohms;

or "the number of amperes flowing in a circuit is equal to the number of volts of pressure divided by the number of ohms of resistance" in the entire circuit. Thus if we have a circuit of 1 ohm total resistance, and we apply a pressure of 1 volt, the current flowing in the circuit will be one ampere, thus :—

$$\frac{1 \text{ Volt}}{1 \text{ Ohm}}=1 \text{ ampere.}$$

If the pressure be doubled the current will also be doubled, thus :—

$$\frac{2 \text{ Volts}}{1 \text{ Ohm}}=2 \text{ amperes.}$$

The current will also be doubled by halving the resistance, thus :—

$$\frac{1 \text{ Volt.}}{.5 \text{ Ohm}}=2 \text{ amperes.}$$

The above equation may also be expressed as follows :—

$$R=\frac{E}{C}(2)$$

$$E=R\times C\ (3)$$

By means of equation (2) the resistance of any circuit can be found if the pressure and current flowing through it is known. For example: if 20 amperes are passing through a circuit at a pressure of 100 volts, the resistance will be—

$$\frac{E}{C} = R \quad \frac{100}{20} = 50 \text{ ohms.}$$

Equation (3) is very useful as a means of ascertaining the pressure required to send a given current through a given resistance; *e.g.*, the pressure required to send a current of 4 amperes through a resistance of 25 ohms will be—

$$C \times R = E.$$
$$4 \times 25 = 100 \text{ volts.}$$

It will be obvious that as the pressure E is wholly expended in forcing the current C through the resistance R, the above equation (3) also measures the fall of potential in any circuit or portion of a circuit.

Circuits.—An electrical pressure being available, it is necessary, in order to have an electric flow, to provide a continuous conducting path from the point of positive potential to the point of negative potential. This path, whether composed simply of wires, or of lamps, motors, or other applications of electric power, is called a *circuit*, and circuits may be divided into two kinds, viz., *series circuits, and parallel or shunt circuits.* In the series circuit (Fig. 2), the wires, lamps, &c., are arranged end to end, so as to form one continuous conducting path connecting the two points of higher and lower potential, and the current in flowing between these points passes in succession through each of the lamps or other appliances composing the circuit. In the parallel or shunt circuit (Fig. 3), two main wires or leads M_1 M_2 are connected to the points of higher and lower potential, and the lamps, wires, &c., are connected across the two mains, or arranged side by side so as to form a

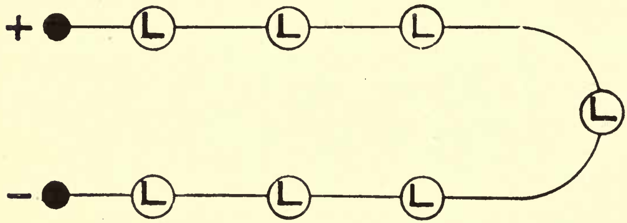

FIG. 2.

number of independent paths or branches, and the current in flowing from the higher to the lower potential divides itself amongst these branches in inverse proportion to their resistance. It will be apparent that the total resistance of the parallel arrangement is less than that of any of its branches, for these being arranged side by side are equivalent

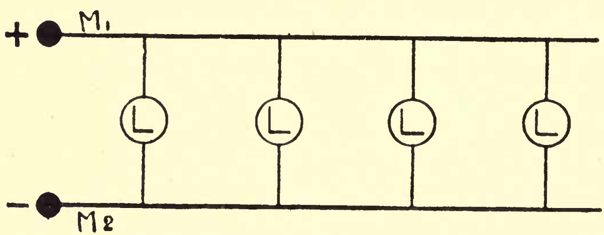

FIG. 3.

to one having a cross section equal to the sum of the cross section of the branches. If the resistances of all the branches are equal, the total resistance of the circuit will be equal to the resistance of one branch divided by the number of branches. The total resistance of the series circuit is evidently equal to the sum of the resistances of each of its separate parts, since these are included in one continuous path; and for the same reason the strength of the current flowing in a series circuit is obviously everywhere the same. A circuit is said to be "closed" when it forms a continuous conducting path, and to be "open" when a discontinuity occurs in some portion such that an electric current cannot flow. When a circuit is connected or bridged across in such a manner, by some conducting material, so as to offer a resistance less than its normal working resistance, it is said to be "cross" or "short" circuited.

Activity or Power.—The activity of an electric circuit, or the rate at which energy is being expended in an electric circuit, may be expressed by any of the following equations:—

$$W = EC \quad (1)$$

$$W = C^2R \quad (2)$$

$$W = \frac{E^2}{R} \quad (3)$$

where E = Electrical pressure or electro-motive force.
C = Current.
R = Resistance.
W = Activity or rate of working.

If E be in volts, C in amperes, and R in ohms, the result will be in *Watts*, the watt being the unit of electric power, and equal to one seven hundred and forty-sixth part of a horse-power. As most installations are in practice provided with an ammeter and voltmeter, the current and pressure may be measured with facility, and therefore equation (1) is most used in practice in determining the activity or power of an electric circuit. To measure the electrical energy of a circuit, the instruments are arranged as represented in Fig. 4; D is a dynamo

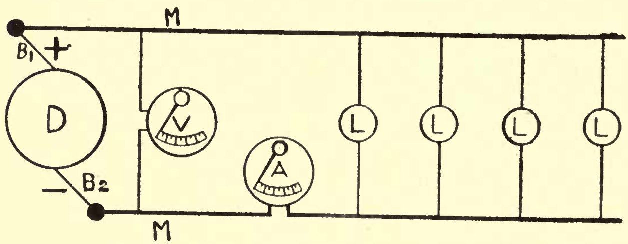

FIG. 4.

or other generator, the positive and negative terminals of which are connected to the two mains M M between which the lamps L L are connected in parallel. To indicate the amount of current flowing in the circuit, an ammeter A is inserted in "series" in one of the mains and with the lamps, and therefore the whole of the current passing to the lamps passes through the ammeter, and is measured by the latter. A voltmeter V is connected across the two main leads, or in shunt with the dynamo, and measures the difference of potential between the two mains in volts. By taking simultaneous readings of the voltmeter and ammeter the energy being expended in the circuit can be ascertained by equation (1). For example, suppose the voltmeter to indicate 100 volts, and the ammeter 100 amperes, then by equation (1) $EC = W$. $100 \times 100 = 10{,}000$ watts are being expended in the circuit. The output of dynamos is usually expressed in watts, as this indicates the actual electrical power given by the machine, irrespective of the strength of the current, or its pressure, which may be varied to any extent so long as their product remains constant. For example, a machine designed for an output of 100,000 watts may be arranged to give 1,000 amperes at a pressure of 100 volts, or 10,000 amperes at 10 volts pressure, or 100 amperes at 1,000 volts pressure. The power required to drive the machine under these varying pressures and currents will remain the same, since their product remains constant. The power required to work incandescent and arc lamps and other electrical appliances is also expressed in watts. A standard candle-power, when produced by an incandescent lamp, requires at the present time an expenditure of 3.75 watts; when produced by an arc lamp, about .5 watts is required. By dividing the output of a machine in watts, by the watts per candle-power as given above, the total candle-power the machine is capable of supplying under the two systems of illumination may be ascertained.

Kilo-watt. — The watt is but a very small unit, and when used for expressing the outputs of the large dynamos in use at the present time leads to inconveniently large numbers; therefore the outputs of such machines are frequently expressed in larger units of 1,000 watts, called *Kilo-watts; e.g.*, a dynamo capable of generating 100,000 watts is called a 100 *Kilo-watt* or a 100 *Unit* machine.

Horse-power.—In practice it is frequently desirable to have the rate of working expressed in horse-power; in this case the energy is first measured in watts, by means of the above formulæ, and afterwards converted into horse-power by dividing by 746, since 746 watts are equivalent to one horse-power. As an example of the practical application of the above, suppose we have a dynamo supplying current to 20–16 candle-power incandescent lamps, and we wish to ascertain the horse-power being expended in driving them; then, as each lamp absorbs 60 watts, $20 \times 60 = 1200$ watts are being expended. Dividing by 746 to bring to horse-power we get 1.6; the electrical horse-power being absorbed by the lamps is therefore 1.6 horse-power. In calculating the mechanical powers required on the dynamo pulley to drive the above load, a further allowance must be made, depending upon the efficiency of the dynamo, on account of the power lost in exciting the dynamo, friction of bearings, &c. Assuming the dynamo to have a commercial efficiency of 85 per cent., the brake horse-power required to drive would be—

$$\frac{1200 \times 100}{746 \times 85} = 1.9 \text{ horse-power.}$$

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CHAPTER II.

MAGNETIC PRINCIPLES.

SINCE the theory of the dynamo is essentially magnetic, it will be necessary, before proceeding to describe its action, to consider the elementary magnetic principles underlying its construction.

The Magnetic Field.—This is the term applied to any space within which the well-known magnetic forces of attraction or repulsion are observable. Everyone knows that there is a limited space or area surrounding the ends or poles of a magnet through which small pieces of iron are attracted, or the ends or poles of other magnets are attracted or repelled, and it is to this space that the term "field of magnetic force," or "magnetic field," is applied. The properties of the magnetic force at any point in a magnetic field may be specified, like a mechanical force, by three quantities, viz., the position or point of application, the direction, and the intensity of the magnetic force; of these three quantities the last two only need, however, be considered in connection with the dynamo.

Direction of Magnetic Force.—The direction of the magnetic force at any point in a magnetic field may be defined as the direction in which a small pivoted magnetic needle points when held in the field at that point. If a small suspended magnetic needle or pocket-compass be placed at various points in the magnetic field surrounding a bar magnet, as

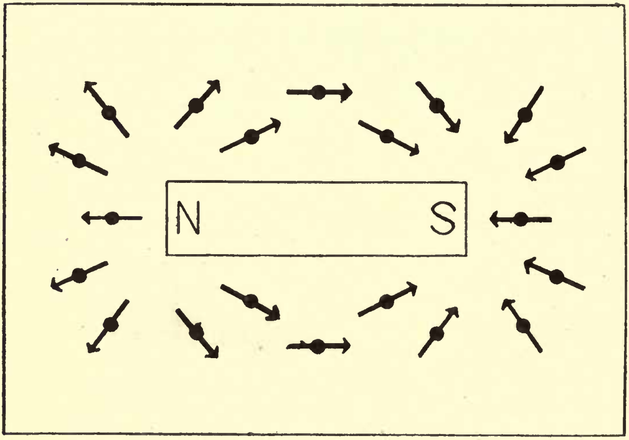

FIG. 5.

represented in Fig. 5, it will be found that the needle always points in a definite direction, which direction varies with its position in the field, the direction of the magnetic axis of the needle at any point representing the direction of the magnetic force at that point.

Lines of Force.—If a magnetic needle, similar to that in the above experiment, be suspended by means of a thread over a bar magnet, and moved from the north to the south pole of the magnet, as illustrated in Fig. 6, the centre of the needle will trace out curving lines connecting the two poles. The paths or lines followed by the centre of the magnetic needle are termed *lines of magnetic force*, and in the modern conception of a magnetic field this latter is assumed to be entirely filled up with these imaginary lines of force. These lines of force are assumed, for reasons to be hereafter understood, to have a certain positive

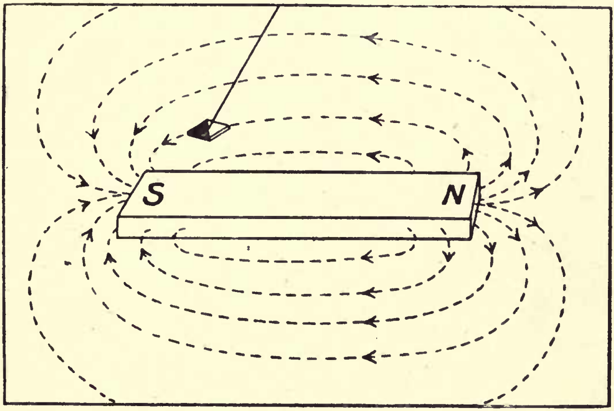

FIG. 6.

direction, namely that direction in which a small north-seeking magnetic pole would tend to move if placed in the magnetic field; or, in other words, the lines of force are assumed to *stream* or *flow* in a direction from the north to the south pole, as indicated by the arrows in Fig. 6.

Intensity or Strength of Magnetic Field.—The relative intensity (and this is all that is required for the present purpose) or strength of a magnetic field at different points may be conveniently expressed by the density or number of lines of force passing through a unit of area at the points in question;

hence where the lines of force are few, the field is weaker than where they are more dense.

Graphic Representation of Magnetic Fields.—The arrangement of the lines of force in any magnetic field may be most expeditiously and conveniently represented by the well known experiment of dusting iron filings upon a sheet of cardboard placed in the magnetic field. In this experiment each of the little particles of iron become magnetised by "induction," and are for the time being transformed into small magnetic needles, which set themselves, in obedience to the attractions and repulsions of the magnetic field, along the directions of the magnetic lines, and

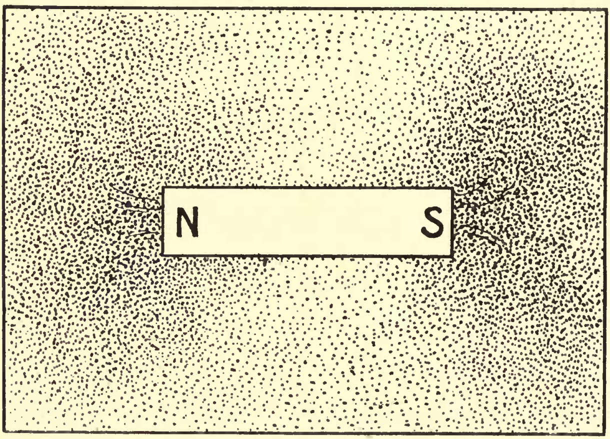

FIG. 7.

thus map out the directions of the magnetic force at every point in the field. The arrangement of the lines of force in the magnetic field of a permanent bar and horse-shoe magnet, as made apparent by this method, is shown in Figs. 7 and 8. It will be seen that the filings arrange themselves in curving lines

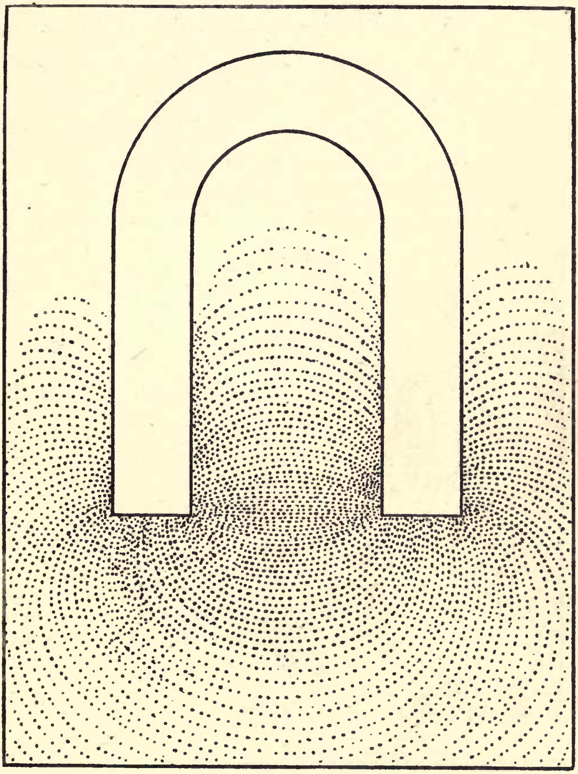

Fig. 8.

connecting the two poles of the magnets. It will also be noticed that the density of the lines and therefore the intensity of the magnetic field is greatest near the poles or ends of the magnets, and that the strength of the field decreases as the distance from the poles increases.

Electro-Magnetism.—When an electric current is passing through a wire or conductor the wire is found to develop magnetic properties. It creates a magnetic field, and attracts or repels the poles of a magnet, and is attracted or repelled by a magnet,

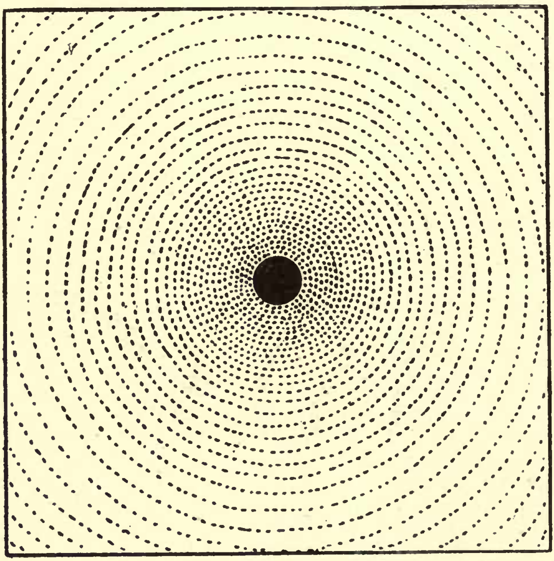

FIG. 9.

according to the nature of the pole and the direction of the current flowing in the wire. The arrangement of the lines of force in the magnetic field surrounding a straight wire or conductor through which an electric current is passing, as made apparent by passing the wire vertically through a sheet of cardboard and sprinkling iron filings thereon, is shown in Fig. 9. It will be seen that the filings arrange themselves in concentric circles around the wire, and that the strength of the field as represented by the density of the lines is greatest immediately around the wire, and falls off as the distance from the wire increases. The wire is in fact surrounded by a sort of magnetic whirl, which may be observed at any portion of the wire, however great its length, so long as the current is passing.

Solenoids.—If a wire, while being traversed by an electric current, is wound up into a spiral coil, the arrangement becomes a "solenoid." The arrange-

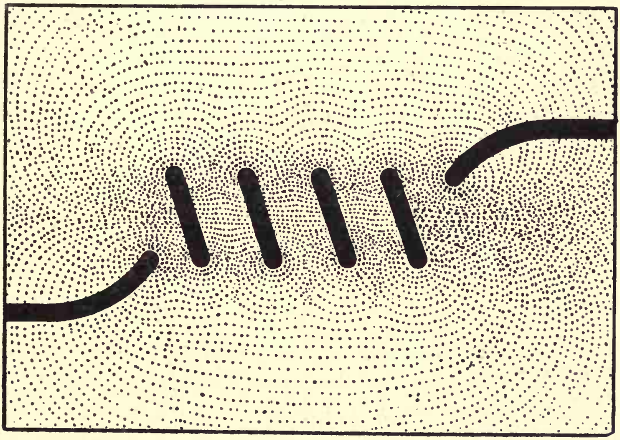

FIG. 10.

ment of the lines of force in the magnetic field surrounding a solenoid is represented in Fig. 10. It will be observed that the lines of force form continuous closed curves running through the interior of the coil, and issuing from one end and entering into the other end of the coil, and that the arrangement of the external magnetic field is very similar to that of a permanent bar magnet of cylindrical form as represented in Fig. 7. A solenoid has north and south poles, and in fact possesses all the properties of an ordinary permanent magnet, with the important difference that the magnetism is entirely under control, for it is found that under all circumstances the strength of the magnetic field of a solenoid is at every point proportional to the strength of the electric current passing through its coils: if the current is increased, the magnetism is increased in proportion also; and if the current is stopped, all trace of magnetism disappears. The magnetic effect or the magnetising power of a solenoid is also proportional to the number of turns of wire composing the coil; hence the magnetising power of 1 ampere flowing through 10 turns of wire is exactly equal to that of 10 amperes flowing through 1 turn, or to that of 5 amperes flowing through 2 turns. The product of the number of turns of a solenoid by the strength of the current flowing through them in amperes is called the *ampere turns* of the solenoid, and the magnetising power of a solenoid is proportional to the ampere turns of the solenoid.

Professor Jamieson's Rules.—If the direction of the electric current flowing through the coils of a solenoid is reversed, the polarity of the solenoid is reversed also,—*i.e.*, that which was formerly the south pole becomes the north pole, and that which was formerly the north pole becomes the south pole.

Professor Jamieson has devised two very useful rules, which are especially applicable in the coupling up of the coils of dynamo field magnets, for ascertaining the polarity of a solenoid when the direction of the current flowing through its coils is known, or *vice versa.*

RULE 1.—To ascertain the polarity of a solenoid when the direction of the current in the windings is known: Place the *right hand* upon the solenoid as

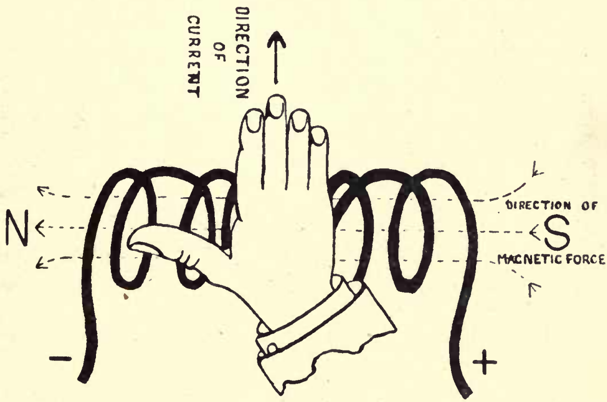

FIG. 11.

shown in Fig. 11, with the fingers pointing in the direction of the current, then the thumb points in the direction of the north pole of the solenoid.

RULE 2.—Ascertain the north pole of the solenoid by means of a compass needle, then by placing your *right hand* upon the solenoid (as shown in the Fig.) so that the outstretched thumb points in the direction of the north pole (or where the magnetic lines leave the coil), the fingers will point in the direction of the current passing through the windings.

Electro-Magnets.—If, whilst an electric current is circulating in the coils of a solenoid, a mass of iron such as an iron bar is introduced into its interior, it is found that the strength of the magnetic field is enormously increased. This increase in the strength of the field is due to the fact that the iron has a less magnetic resistance than the air, or a greater conductibility for the lines of force, and therefore a greater number of lines pass through the iron than what previously passed through the air. With well annealed wrought-iron the "induction," or number of lines of force, passing through a unit of area of cross section may be increased in the ratio of 1 : 2000, or for every line passing through a unit of area of air 2000 would pass through an equal area of wrought-iron. This property of wrought-iron is taken advantage of in the construction of *electro magnets*, by means of which much more powerful magnetic effects may be produced than by the use of simple solenoids or permanent magnets. An electro magnet is merely a solenoid provided with an iron core of varying form. As previously mentioned, the strength of the magnetic field of a solenoid is strictly proportional to the strength of the current flowing in its coils; this, however, is no longer true when the solenoid is provided with an iron core or becomes an electro magnet, for the reason that the magnetic properties of the iron alters with the strength of the magnetic field. At first, the presence of the iron enormously increases the strength of the field; after a time, however, as the strength of the current flowing in the exciting coils is increased, the conductibility of the iron for the lines of force appears to decrease, until a point is eventually reached when the presence of the iron core appears to have no effect whatever in increasing the strength of the field. At this stage the iron core may be regarded as being *saturated* with lines of force, and any further increase of magnetising power will produce only a slight increase in the strength of the field, any such increase being that due to the effect of the coils alone acting merely as a simple solenoid.

Curve of Saturation of Electro-Magnet.—The magnetic behaviour of the iron core of an electro-

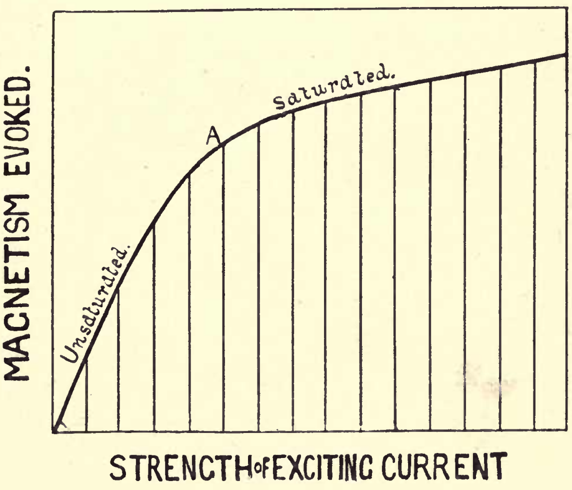

FIG. 12.

magnet can best be studied by reference to Fig. 12, which represents the *curve of saturation* of the electro magnet. The strength of the magnetising current is represented horizontally, and the magnetism evoked vertically. It will be seen that the curve rises from zero, at first, at a very steep angle, thus showing that a small increase in the strength of the magnetising current produces a great increase of magnetism; after a time, however, as the exciting current is increased, the conductibility of the core for lines of force decreases, and the curve then commences to bend over as at A; as the strength of the exciting current is still further increased the iron core becomes saturated, and adds nothing to the strength of the field, as is indicated by the curve being almost horizontal. The slight increase in the strength of the field, which is indicated by the curve being inclined at a small angle to the horizontal, is due solely to the effect of the coils alone, and it will be noted that a very great increase of exciting current is required at this stage to produce the small effect in the strength of the field indicated.

Residual Magnetism.—When a mass of iron, such as a bar, has once been magnetised, either by means of the electric current or a permanent magnet, it becomes a difficult matter to entirely remove all traces of magnetism from the iron when the magnetising agent has been removed, and as a general rule a small amount of magnetism is permanently retained by the iron. The magnetism so retained by the iron is known as *residual magnetism*, and it varies in amount with the quality and physical and chemical composition of the iron. Well annealed pure wrought-iron as a rule possesses very little residual magnetism, while on the other hand wrought-iron which contains a large percentage of carbon or other impurities, or which has been subjected to some hardening process such as hammering, rolling, stamping, &c., and cast-iron, possesses a very large amount of residual magnetism. This property of residual magnetism in iron is of great importance in the working of the *self-exciting* dynamo, and is indeed the essential principle of this class of machine.

CHAPTER III.

THEORY OF THE DYNAMO.

THE construction and action of all dynamos is based upon the principle of electro-magnetic induction discovered by Faraday in 1831. Faraday found that currents of electricity are generated in all good electrical conductors by causing them to cut the lines of force contained in a magnetic field.

Cutting Lines of Force.—Reference to Fig. 13 will render clear what is meant by the term "cutting

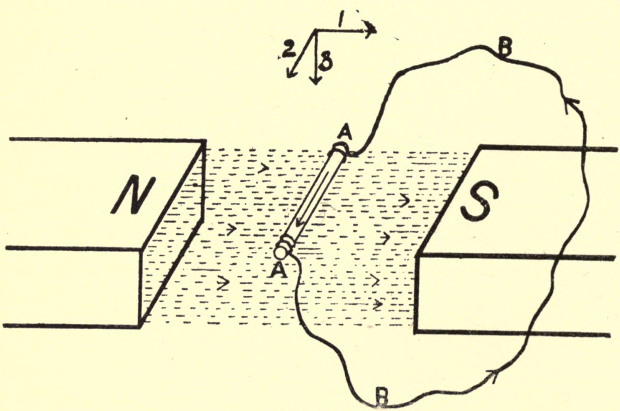

FIG. 13.

the lines of force." In this diagram A A is a conductor, capable of being moved in any direction through the lines of force proceeding from the north to the south poles of the magnet N S. The two ends of the conductor A A are joined together by the flexible connecting conductor B B, which, not being included in the magnetic field, may be assumed to be removed from its influence. If now relative motion takes place between the conductor A A and the lines of force, it will be at once apparent that the conductor in its motion may either simply *slide* along, or *cut* through, the lines of force. If the conductor is moved along the lines of force in the direction of the arrow (1), *i.e.*, parallel to the lines of force, it will merely slide through the lines without cutting them in any way, and in consequence no electro-motive force or current will be "induced" or generated in the conductor. Again, if the movement is in a direction coincident with the length of the conductor, as indicated by the arrow (2), the motion may again be regarded as merely a sliding one, and again no electro-motive force will be generated. If, however, the conductor is moved downwards in the direction of the arrow (3), *i.e.*, in a direction at right angles to the lines of force, an E. M. F. will be at once induced in the conductor, for the latter in its motion "cuts" through the lines of force. The direction in which the E. M. F. acts, and in which the resulting current flows in the conductor, in the particular case illustrated, is indicated by the arrow marked upon the conducting circuit. The electro-motive force and current thus induced, by the relative motion of a conductor and magnetic field, only exists so long as the conductor is actually cutting the lines of force, and immediately ceases as soon as the conductor moves out of the magnetic field or the motion itself ceases. In all cases the value of the E. M. F. induced is directly proportional to the rate of cutting lines of force, or to the number cut per second; the greater the speed of the conductor, and the greater the strength of the magnetic field, the greater being the value of

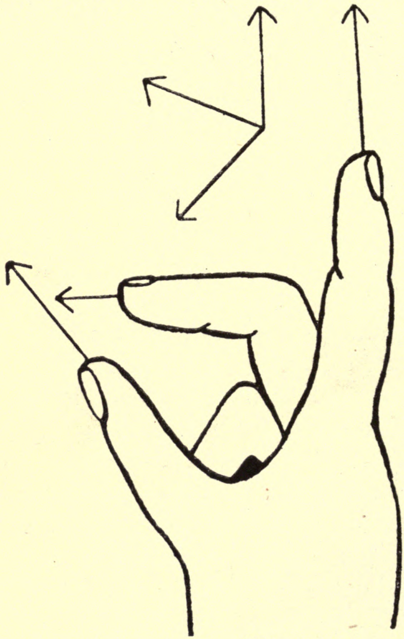

FIG. 14.

the electro-motive force induced. If the direction of motion of the conductor is reversed, *i.e.*, if it is moved through the lines in an upward direction, the direction of the E. M. F. induced in the conductor will be reversed also; or if, whilst the conductor is moving downwards, the direction of the lines of force is reversed by changing the position of, or reversing the poles of, the magnet, the same thing will occur; from this we see that a definite relation exists between the direction of motion of the conductor, and of the magnetic lines, and of the E. M. F. induced. As in the practical applications of the dynamo it is frequently necessary to refer to this relation, a number of rules have been devised with the object of facilitating its remembrance, of which that due to Professor Fleming, illustrated and described below, is probably the simplest and best.

Professor Fleming's Rule.—Spread out the thumb and first two fingers of the right hand in such a manner that each will be at right angles to the others, as represented in Fig. 14. Then if the thumb be pointed in the direction of motion of the conductor, and the forefinger in the direction of the lines of force, that is, from the north pole to the south pole of the magnet, the middle finger will be pointing in the direction in which the E. M. F. induced in the conductor acts, or in which the current flows.

Simple Dynamo.—We have already seen that the E. M. F. and current induced in a conductor only lasts so long as the conductor is actually cutting the lines of force; hence, in order to keep a current circulating in a conducting circuit by means of this principle, it is necessary to keep the conductor continually cutting the lines of force. This is most conveniently effected by fixing the conducting circuit upon a spindle, and revolving it in a magnetic field. An arrangement of this description is represented in Fig. 15, where A A is a spindle capable of revolving in the magnetic field between the north and south poles of the magnet N S

To this spindle is fixed the conducting circuit C C, the two ends of which are connected to two metallic rings fixed upon the spindle, and insulated from it

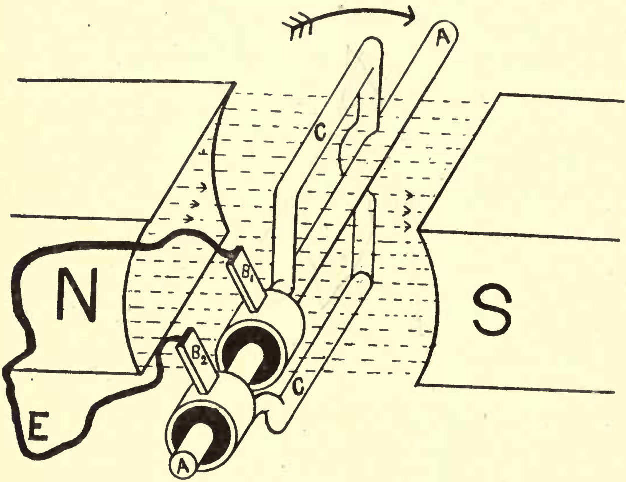

FIG. 15.

and from each other. Two brass brushes, B1, B2, press upon each of these rings, and serve to convey the current generated in the conducting circuit C C to the external circuit E. If now the loop be first placed in the vertical plane, as shown, the lines of force will thread through it at right angles. As the loop is moved through the lines of force in the direction of the arrow during a complete revolution, the limbs of the loop will cut through the lines of force; and in consequence, E. M. F.s and currents will be generated in the loop which, on applying Professor Fleming's rule, will be found to be directed as follows:—Whilst the loop is passing from 0° to

180°, or through half a revolution, the E. M. F. and current induced in the limb descending on the right will be directed from back to front, and in the opposite direction, *i.e.*, from front to back, in the limb which is ascending on the left. On passing the 180° position, the limb which was previously descending on the right will begin to ascend on the left, and the limb which was previously ascending on the left will now begin to descend on the right. On passing the 180° position, the limbs will therefore have E. M. F.s and currents induced in them opposite in direction to those which previously flowed through them during the first half-revolution. As a result, the current flowing in the external circuit E will also be reversed at every half-revolution of the spindle, or the current will be an *alternating* current. As the value of the E. M. F., and consequently the strength of the current, generated in the conductor by its motion in the magnetic field is dependent upon the rate of cutting lines of force, or upon the number cut per second, we may examine how this varies during a complete revolution. As the loop moves out of the vertical plane during the first quarter-revolution, it at first moves nearly parallel to the lines of force, and consequently the rate of cutting lines is a minimum. As the rotation is continued, the rate of cutting lines gradually increases, until, upon reaching the horizontal position, the loop moves at right angles to the lines of force, and the rate of cutting lines is therefore a maximum.

Upon moving out of the horizontal position the rate of cutting lines will gradually decrease until a half-revolution has been completed, when the loop will again be moving parallel to the lines, and consequently the rate of cutting lines will again be a minimum. The same thing will be repeated during the remaining half-revolution, with the difference that the E. M. F. and current will be reversed in direction, as already explained. From this it will be seen that the E. M. F. and current generated in the loop during the first quarter-revolution, or from 0° to 90°, will rise from zero to a maximum value, and then fall to zero again during the completion

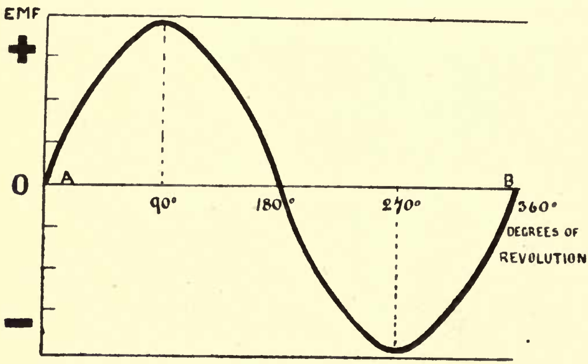

FIG. 16.

of the half-revolution, or from 90° to 180°. From 180° to 270° the E. M. F. will again rise from zero to a maximum, and again fall to zero as the loop moves from 270° to 360°. This rise and fall of the E. M. F. during a complete revolution of the loop is graphically represented in Fig. 16, where the various positions of the loop during a complete revolution are indicated upon the horizontal line A B, which also indicates zero potential, and the vertical lines represent the value of the E. M. F.

set up in the loop at these positions. The portion of the curve above the horizontal line indicates the positive direction of the E. M. F. generated during the first half-revolution of the loop, that portion below the line the reverse negative direction produced by the second half-revolution.

Commutating Current.—The arrangement of the loop or conducting circuit, as described above, constitutes what is known as an *alternating current* dynamo. By far the larger number of the practical applications of electricity are effected, however, by

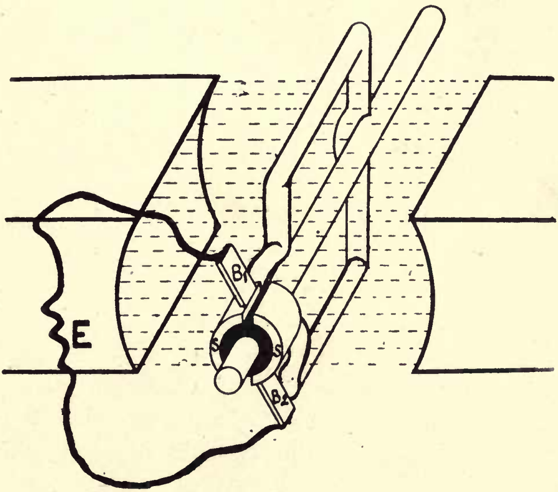

FIG. 17.

means of continuous currents generated by *continuous current* dynamos. In this class of machine the necessary alteration in the direction of the current is effected by a process called "commutation," the appliance for effecting the alteration in the direction of the current being called a "commutator." This appliance, in its simplest form, consists of two metallic segments S S, insulated from each other by means of a cylinder of boxwood or other insulating material, as shown in Fig. 17. The circuit is arranged upon a spindle as before, and the commutator is fixed upon the spindle in place of the two rings, and one end of the conducting coil or loop is connected to each of the segments. Two metallic brushes or springs, B1, B2,

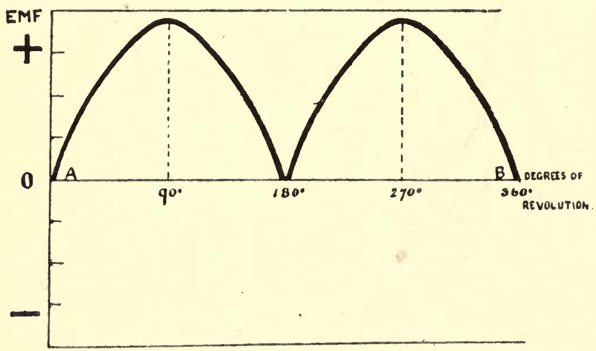

FIG. 18.

press upon the segments, and convey the current generated in the coil to the external circuit E, as indicated. Upon a little consideration, it will be apparent that, if the springs are so placed that one segment slides out of contact as the other slides into contact with the brushes, at the moment the current is reversed in the coil, during certain periods of revolution, the current flowing in the external circuit will be "commutated," or will always flow in one direction, although the relative directions of the current flowing in the revolving coil or loop will be unaffected.

Pulsating Currents.—Although the application of the commutator to the coil has the effect of causing the current to flow always in the same direction in the external circuit, it has no effect whatever upon the *value* of the E. M. F., or the strength of the current, during a complete revolution of the coil. This still remains as before, as will be seen by reference to Fig. 18, which represents the nature of the E. M. F. generated in the loop when fitted with a commutator. It will be seen that the current is a pulsating current, rising from zero to a maximum and then falling to zero again, but always flowing in one direction, as denoted by both curves being above the horizontal or zero line A B.

Value of E. M. F.—The electro-motive force set up in any conducting circuit by its motion in a magnetic field is proportional to the speed at which the conductor moves, and to the number of lines of force cut by the conductor, or—

$$E = S\ N.$$

where E = Electro-motive force.
S = Speed of conductor.
N = Number of lines of force.

Hence, in order to increase the electro-motive force of the elementary form of dynamo illustrated above, we may increase either the speed of the coil or the number of lines of force threading through it, this latter being accomplished either by increasing the magnetising force applied to the electro magnet producing the magnetic field, or by winding the loop upon an iron core of suitable shape, thus reducing the magnetic resistance of the air space between the poles of the magnet. The E. M. F. may also evidently be increased by winding a greater number of turns or loops around the iron core, each being connected in series with the other, so that the E. M. F. of one is added to that of another, thus making the total E. M. F. of the coil equal to the sum of the E. M. F.s of each of the conductors or loops. The combination of the coil and iron core, when thus arranged, is called an "*armature*," and the electro magnet which creates the magnetic field in which the armature revolves is called the "*field magnet;*" and every dynamo consists essentially of these two parts, and of these two parts and a "*commutator*" when the dynamo is required to generate "direct" or "continuous" currents.

Parts of Dynamo.—The nature and uses of the different parts of a dynamo will be understood by reference to Fig. 19, which represents a complete machine. In this type of dynamo, as in the majority of continuous current dynamos, the magnetic field is stationary whilst the armature revolves in it. The magnetic field in the particular dynamo illustrated is produced by the iron horse-shoe electro magnet M, which is excited by the current flowing in the magnetising coils E E. The ends or poles of the field magnet M are bored out so as to form a circular chamber within which the armature A rotates. This latter consists of an iron core rigidly fixed to a steel shaft or spindle S, which revolves in the two bearings F F. Upon one end of the shaft is fixed the driving pulley P.

The iron core is overwound with a large number of insulated copper conductors or coils, the ends of which are connected to the circular commutator C. Two stationary metallic brushes, B B, press upon the latter, and convey the current generated in the coils of the armature through the flexible conductors or "leads," L L, to the terminals T T, from whence it is conveyed to the external or working

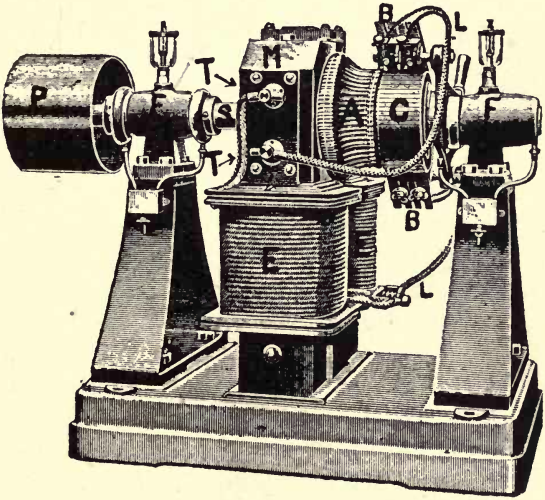

FIG. 19.

circuit. When the machine is in action, the armature and conductors or coils are caused to rotate within the magnetic field, produced by the electro magnet M, by means of a belt passing over the pulley P. In consequence, E. M. F.s are induced in the conductors, which, on being commutated at the commutator, are transmitted through the medium of the brushes and flexible leads to the two terminals T T, giving rise to a difference of potential between the latter. This difference of potential may be wholly utilised for the purpose of supplying current to an external circuit, if a separate dynamo is used for exciting the field; or the ends of the field coils may be connected to each of the terminals, when the machine will supply current to its own field magnets. So long as merely an E. M. F. is acting in the armature, and no current is flowing in its conductors, these latter offer no resistance to the motion, and the only mechanical energy expended will be that necessary to overcome the resistance due to the friction of the bearings, &c. As soon, however, as current commences to flow in the conductors, a magnetic field is created around each (as represented in Fig. 9), and this, reacting on the magnetic field produced by the field magnet, exerts an attracting or repelling force, as the case may be, and thus tends to retard the rotation of the armature. In consequence, a greater amount of mechanical energy must be expended in keeping the armature rotating at its normal speed, the amount of energy so expended being directly proportional, if the pressure is kept at a constant value, to the current flowing in the armature.

CHAPTER IV.

ARMATURES.

THE elementary form of armature described in the preceding chapter (Fig. 17) possesses the disadvantage that the current generated in it by its motion in the magnetic field, though always flowing in one direction in the external circuit, is not absolutely continuous, but is a pulsating current consisting of two sharp impulses to every revolution of the spindle. As these pulsations are evidently due to the coil moving alternately into and out of the positions of best and least actions in the magnetic field, it will be evident that if an additional coil is arranged at right angles to the existing coil, so that one coil is in the position of best action, whilst the other is in the position of least action in the magnetic field, the resulting current will be more nearly continuous. That such is the case will be seen by reference to Fig. 20, which represents the resultant curve due to such a combination of coils; it will be seen that the crests of the curves are much closer together, and approach more nearly to the straight line, which would represent the current if it were absolutely continuous. A little consideration will show that if we thus keep on arranging coils between the existing ones, a time will eventually be reached when the curves so overlap each other that they may be represented by a practically straight line, when the resulting current will be, to all intents and purposes, continuous. It is upon this principle that the armatures in practical use are

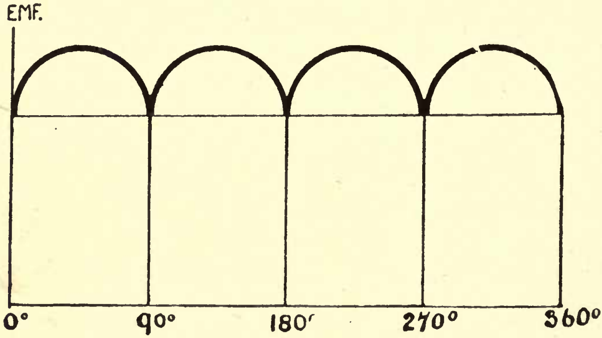

FIG. 20.

constructed, a large number of coils being employed, suitably arranged upon an iron core, so that a large proportion of them are always actively cutting the lines of force, or moving in the positions of best action in the magnetic field.

Types of Armatures.—There are several different methods of arranging the coils upon the iron armature, but the object of all of them is to obtain the practical continuity of the current. The types of armature in most extensive use at the present time are the following:—

The Ring or Gramme Armature, in which the coils are arranged upon an iron ring.

The Drum or Siemens Armature, in which the coils are arranged upon the surface of an iron cylinder or drum.

Each of these forms of armature has its special advantages, and in a general way it may be said that whilst the ring armature is more suitable for generating small currents at high potentials, the drum is better adapted for producing moderate potentials and large currents.

The Ring or Gramme Armature.—The principle of this armature is shown diagrammatically in Fig. 21. An iron ring capable of revolving upon an axis is

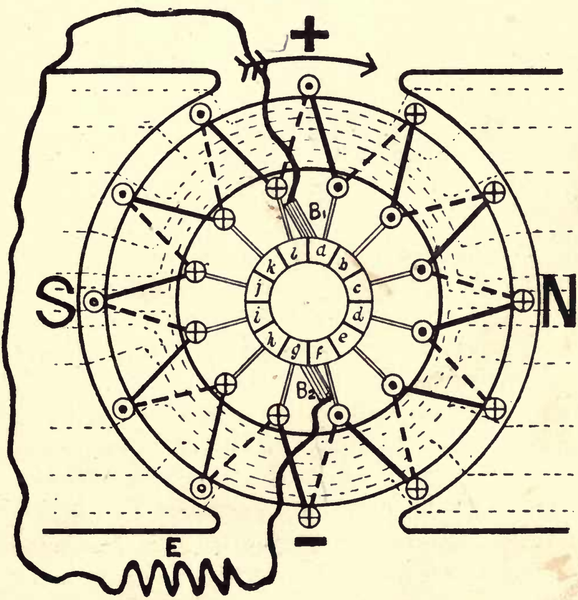

FIG. 21.

arranged in the magnetic field between the poles N and S of an electro magnet. Upon this ring is wound a number of coils or loops of insulated copper wire, so as to cover the whole of the surface of the iron ring. The ends of each of the coils are connected to the ends of adjacent coils, so that a continuous closed spiral is formed all round the ring; and at the points where connection is made between the coils, connection is also made to strips of copper which are insulated from each other, and arranged around the axis of rotation into a circular commutator, as shown in the figure. Against the two strips situated at opposite ends of a diameter press two metallic brushes, B1, B2, which, remaining stationary, serve to convey the current generated in the coils of the armature to the external circuit E. The arrangement of the lines of force in the magnetic field between the two poles N and S, when the ring is inserted therein, is shown by the dotted lines in Fig. 21. From this it will be seen that the lines of force issuing from the north pole pass by way of the armature core to the south pole of the magnet, one half of the lines passing through the upper portion of the core, and the other half passing through the lower portion of the core. Owing to this peculiar arrangement, a very intense magnetic field is created between the outer surface of the armature core and the polar faces, whilst the interior space within the core remains almost entirely free from lines of force.

If the armature core be rotated in the direction of the arrow, the whole of the conductors, being immovably fixed to the core, must necessarily partake of the movement; and therefore all the conductors arranged upon the exterior surface of the ring, moving in the magnetic field in the spaces between the outer surfaces of the ring and the two polar faces, will cut the lines of force contained in this magnetic field, and therefore E. M. F.s will be generated in each of the conductors in consequence. The directions in which these E. M. F.s act, as found by Professor Fleming's rule, is indicated by the dots and crosses marked upon the conductors in Fig. 21. The dots represent the direction of the E. M. F.s when acting from back to front, and the crosses the direction when acting from front to back. As will be seen by this indication, in the conductors moving in the left-hand space the E. M. F.s are directed from the back of the armature to the front, whilst in all the conductors moving in the right-hand space the E. M. F.s are directed from the front to the back of the ring. As we saw in the elementary form of armature described in Chapter III., no E. M. F.s will be induced in the conductors moving in the spaces at the top and bottom of the ring between the two poles of the magnet, for these conductors are moving parallel to the lines of force, nor will any E. M. F.s be generated in the conductors arranged upon the interior surface of the armature, since these conductors are removed from the influence of the lines of force. These interior conductors, although inactive in the production of E. M. F.s, are essential however for the connection of the various active conductors one to another. The coils shown upon the ring in Fig. 21 being wound right-handedly, it follows that the E. M. F. induced in each of the conductors upon both sides of the ring will be added to that of the next above it; consequently the E. M. F.s in all the conductors upon each side of the armature will be directed from the bottom to the top of the ring, which will therefore have a higher or positive potential, whilst the bottom of the ring will have a lower or negative potential, as indicated by the signs in the figure. It will be apparent that if the coils were wound left-handedly, just the reverse would take place, the E. M. F.s being all directed from the top to the bottom; or the same thing would occur if the right-handed winding were retained, and the direction of rotation reversed. Since the total or resultant E. M. F.s of each side of the armature is equal to the sum of the E. M. F.s generated in each of the conductors arranged upon either side of the armature, it follows that if these latter are equal in number the resultant E. M. F.s will be equal and opposite; and, consequently, if the external circuit is open, no current will flow in any portion of the windings, the E. M. F.s merely giving rise to a difference of potential between the top and bottom of the ring. If the external circuit is closed, the current which results will, owing to the two halves of the ring being in parallel, flow up the windings on each side of the ring to the top brush, and from thence through the external circuit to the bottom brush, and thus complete the circuit.

The Drum or Siemens Armature.—This type of armature differs essentially from the ring armature only in the manner in which the conductors are arranged upon the iron core. In the ring armature the core consists of a ring, and is overwound with conductors passing along the outer surface and through the interior; in the drum armature, the core is in most cases a ring also, or may be regarded as a ring, and is overwound with conductors passing along the outer surface, but in place of passing through the interior the conductors are carried completely around it axially, in the manner represented in Fig. 22. This shows a drum armature in perspective, upon which only two adjacent conductors or coils have been wound. Since the windings of the drum armature pass over the ends of the core, it is impossible to represent the whole of them in perspective, and there-

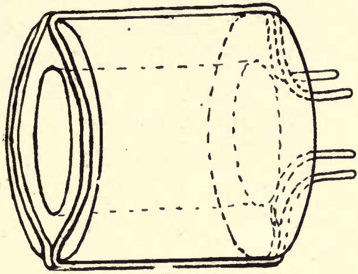

FIG. 22.

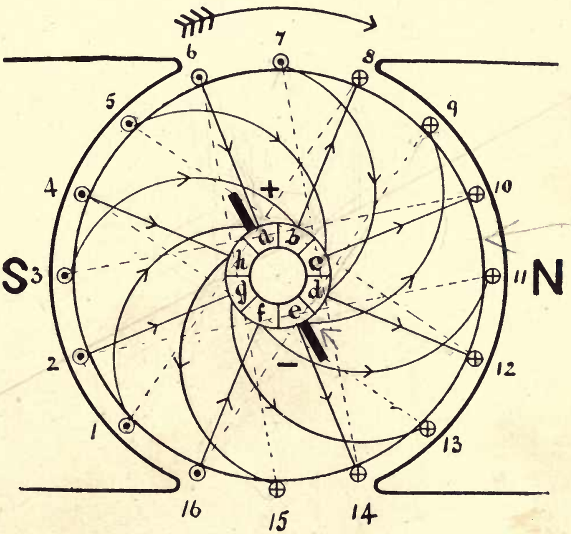

FIG. 23.

fore they are exhibited diagramatically in Fig. 23, which illustrates what is known as a right-handed winding, with eight-part commutator. In the figure shown, the windings are supposed to be viewed from the commutator or front end of the armature. The windings passing along the length of the drum are represented by the small circles, upon which are marked the dots and dashes denoting the direction of the E. M. F.s induced in the conductors, as in the ring armature. The connections passing across the back end of the drum are represented by the dotted lines, those upon the front end by the full lines. The manner in which the individual loops or coils are arranged and connected to each other and to the commutator, will be rendered clear by following the course of a single loop or coil upon the armature. Starting from the commutator segment (*a*), upon which the positive brush is resting at the upper portion of the armature, the conductor proceeds up the face of the drum to 6, thence along the top and across the back end to the lowest point of the drum, from whence it proceeds along the bottom of the drum to 15. From 15 the conductor is brought round the face of the drum and connected to the commutator segment (*h*), next to the one from which it started. Another coil starts from the segment (*h*), and follows a similar course upon the surface of the armature, and is connected to the segment (*g*), from which another coil starts, and so on all round the armature. A continuous closed spiral is thus formed all round the armature, in a somewhat similar manner to the ring armature. The arrangement of the lines of force in the magnetic field, when the armature is inserted therein, is similar to that of the ring armature; and with the armature rotating in the direction indicated by the arrow, it will be seen that the E. M. F.s and currents induced in the conductors, on either side of the armature, have the same relative directions as those induced in the conductors arranged upon the outer surface of the ring armature, the only difference being that the current flows across each end of the drum in place of flowing through the interior; the conductors at the ends being thus the

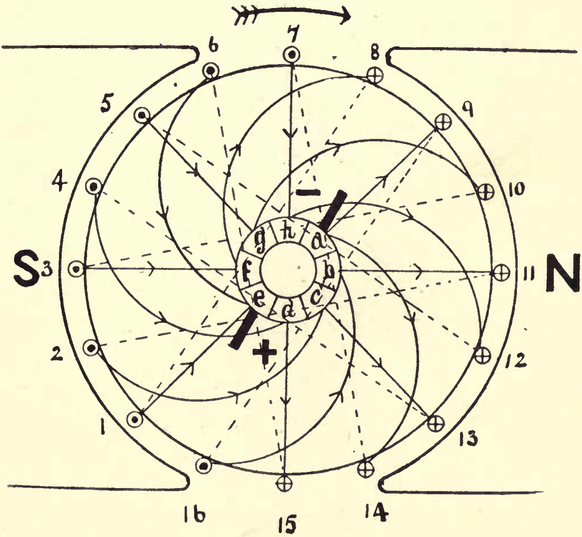

FIG. 24.

only idle portions of the winding in the drum armature. With the particular winding shown in Fig. 23, *i.e.*, a right-handed winding, the E. M. F.s will be directed from the bottom to the top of the armature, in a similar manner to the ring armature, the direction of the E. M. F.s being reversed by reversing the direction of rotation, or by employing the left-handed winding shown in Fig. 24.

Multipolar Ring and Drum Armatures.—In practice it is found that although the ring and drum forms of armature, revolving in a bi-polar field, as described above, forms a most efficient arrangement for moderate outputs up to about 180 kilowatts,

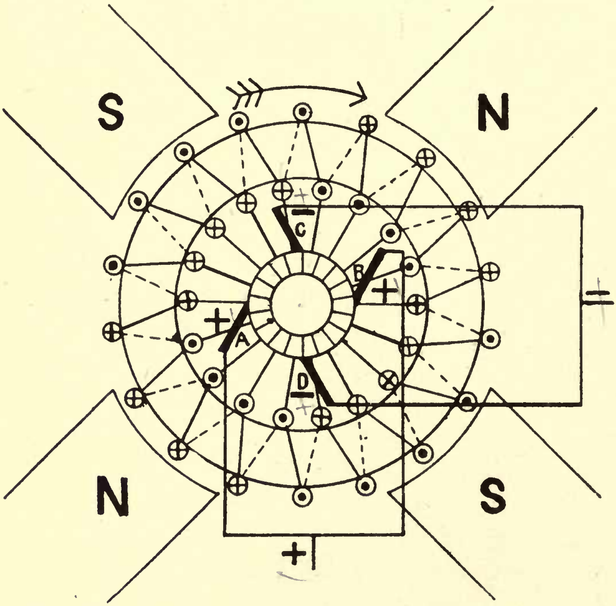

FIG. 25.

when larger outputs are required from a single machine it is more economical to arrange the armature in a field composed of 4, 6, 8 or more poles. In this case the conductors are arranged upon the surface of the ring and drum cores so as to form closed spirals as before, the only difference being that the number of neutral points, or points of collection of the current upon the commutator, is increased in proportion to the number of poles; and in the case of drum armatures, that the loops or coils span a smaller

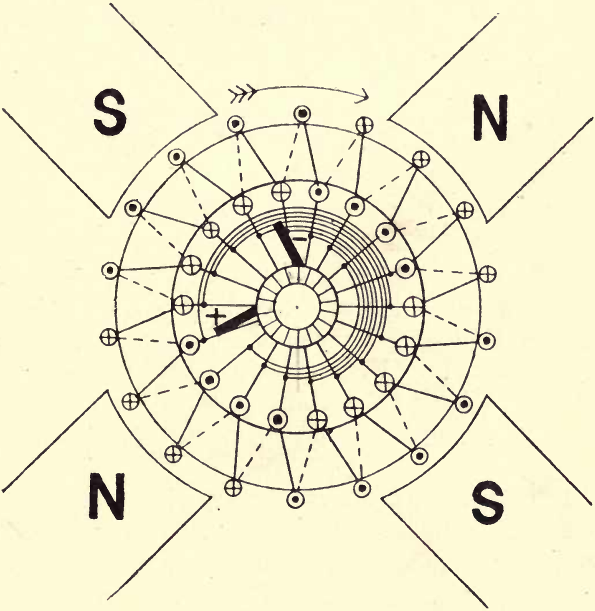

FIG. 26.

proportion of the circumference of the armature. Referring to Fig. 25, which represents a ring armature rotating in a 4-pole field, it will be seen that the coils are arranged upon the core, and connected to the commutator in precisely the same manner as the bipolar ring armature described above. The multipolar armature, as shown, differs however in the fact that, when rotating, it produces two places at equal positive potentials and two places at equal negative potentials upon its commutator, at which the current may be collected, these points being indicated by the position of the brushes in the figure. To collect the current, the two brushes (A B) at equal positive potentials, and the two brushes (C D) at equal negative potentials, are connected together and to the external circuit, as represented. Another method of connecting, which necessitates the use of two brushes only, is illustrated in Fig. 26. In this arrangement, such bars of the commutator as are at the same potentials are connected together. In the case of a 4-pole armature, each of the commutator bars are electrically connected to the one situated diametrically opposite, and the positions for the brushes are at right angles, as represented in Fig. 26; in a 6-pole armature, the three segments of the commutator, situated at 120° apart, are connected together, the brushes being placed 60° apart.

Multipolar Drum Armatures.—Figs. 27 and 28 represent diagramatically the windings of multipolar drum armatures when arranged in parallel and series groupings respectively. In the former grouping, the windings are arranged in as many parallels as there are poles; in the 4-pole field illustrated, the armature is therefore equivalent to a pair of bi-polar drum armatures, each carrying half the total current. The same sequence of winding is used as in the bi-polar drum armatures (Figs. 23 and 24), the only difference being that the wires passing over the ends of the core span approximately only one-quarter in place of one-half the circumference of the armature. In the series grouping (Fig. 28), the windings are arranged in two parallels, with any number of poles; the total E. M. F. of the armature is therefore equal to the sum of the E. M. F.s induced in the conductors, arranged in series between the brushes as in the ordinary bi-polar drum

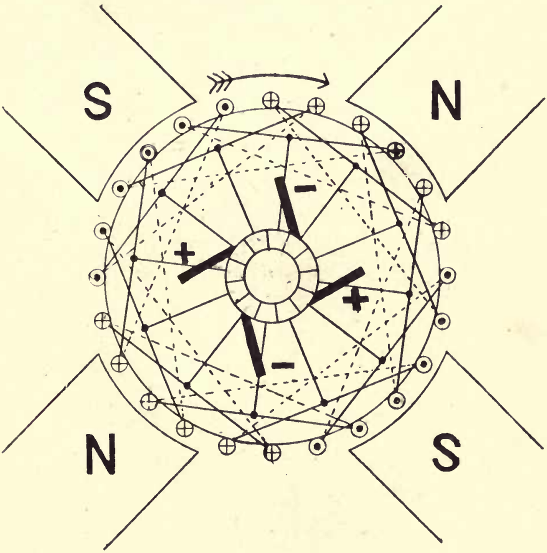

FIG. 27.

armature. Since in this grouping the windings are arranged in two parallels, it follows that two sets of brushes only are required, without any cross connecting of the commutator. Their position upon the commutator varies with the number of poles; when the field magnet consists of 4 poles, the brushes are placed 90° apart, or at right angles, as represented in

Fig. 28; when consisting of 6 poles, the brushes are placed at opposite extremities of a diameter of the commutator as in bi-polar armatures; and when consisting of 8 poles, they are placed 45° apart.

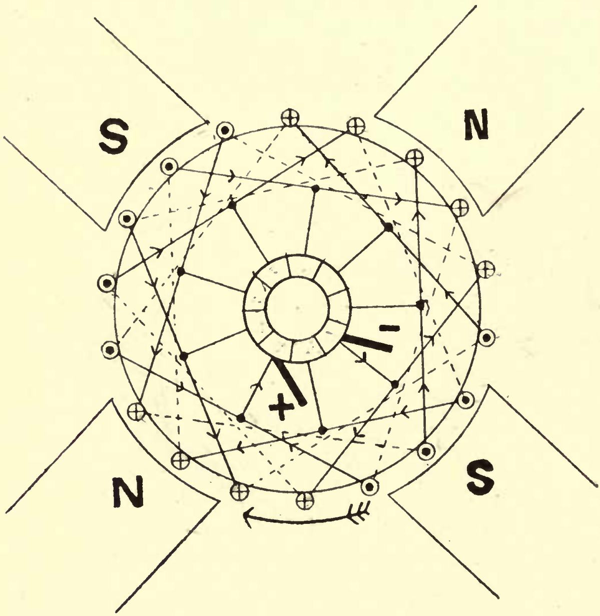

FIG. 28.

Position of Brushes on Commutator.—In all dynamos, both bi- and multipolar, there are certain positions upon the commutator at which the brushes may be placed with a minimum of sparking. These positions are called the *neutral points*, and, as will be seen on examination of Figs. 21 to 28, the position of these neutral points varies with the type of field magnet and winding of armature. In ordinary bi-polar dynamos the neutral points lie at opposite ends of a diameter of the commutator, which diameter is called the *neutral line.* In most dynamos these neutral points do not occupy a fixed position upon the commutator, but vary their position from time to time as current is taken from the machine. When the armature is not supplying current to the external circuit, the neutral line, in bi-polar dynamos, occupies a position at about right angles to a line joining the middle of the pole pieces, or at right angles to the direction of the lines of force in the armature; but as current is taken from the armature, the neutral line shifts round in the direction of rotation, when the brushes must also be shifted round through a certain angle to the corresponding neutral points, if sparking at the brushes is to be avoided. The altered position of the brushes is known as the *lead* given to them, and the angle through which they are moved is known as the *angle of lead.* In all dynamos the lead is forward, or in the direction of rotation of the armature.

Causes of Sparking.—Sparking at the brushes of a dynamo is due to several causes, but mainly to the short-circuiting by the brushes of the armature coils while actively cutting the lines of force. An inspection of Figs. 21 and 23 will show that the ends of each of the coils of the armature are connected to two adjacent segments of the commutator, and that each of the brushes is sufficiently broad to bear upon two bars of the commutator. Hence when each of the coils, during a certain period of the revolution, passes underneath the brushes, each will be momentarily short-circuited by the brushes bridging across the two segments to which the ends of the coils are connected. If this short-circuiting takes place while the brushes are on the neutral points, the coil will be moving mostly parallel to the lines of force, the E. M. F. acting in it will be almost zero, and, in consequence, no sparking will result. If however the brushes are shifted out of the neutral points, either to the right or left, the coil will be short-circuited whilst still actively cutting the lines of force, and an E. M. F. will consequently be acting in the coil. This E. M. F., though small, may produce a very large current, momentarily, owing to the very low resistance of the short-circuited coil. When therefore the short-circuit is opened by the rotation of the commutator, this current, owing to its property of "self-induction," or "electric inertia," does not immediately die out, but continues to flow across the gap for a brief interval, and expends its energy in the form of sparks, which rapidly wear away the commutator and brushes.

Distortion of Magnetic Field.—As soon as a dynamo commences to supply current to a circuit, a number of reactions between the armature and magnetic field immediately takes place. The chiefest of these reactions is the distortion of the magnetic field, and consequent shifting of the neutral points. This distortion of the magnetic field is directly due to the fact that the armature, when working, becomes itself an electro magnet, the poles of which exert an attracting or repelling force upon the magnetic field. The nature of this armature magnetism will be understood by reference to Fig. 29. It will be seen that the currents generated in the windings on each side of the armature, by its motion in the magnetic field, are flowing from the top to the bottom of the ring. On applying the rule given on page 21, it will be found that these currents tend to produce north and south poles on each half of the core at the points where the current enters and leaves the armature. There will thus be two north poles at the top of the ring, and

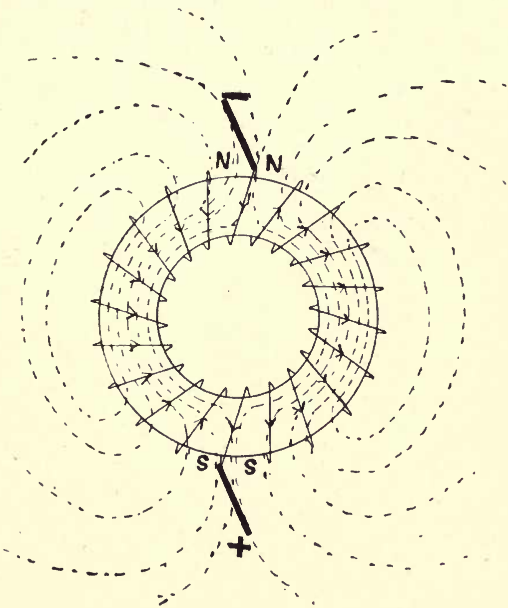

FIG. 29.

two south poles at the bottom; but as these poles are adjacent to one another, the external effect will be equivalent to a single north and south pole situated at the top and bottom of the ring. The resultant effect of these two armature poles upon the magnetic field is to twist the line of force round into an oblique direction, as indicated in Fig. 30. Since in order to secure sparkless collection of the current, and to obtain the greatest difference of potential between the brushes, it is necessary to place these latter at points situated at right angles to the direction of the lines of force in the armature, this twisting of the lines necessarily involves the shifting of the brushes round the commutator in the direction of rotation, otherwise the armature coils will be short-circuited by the

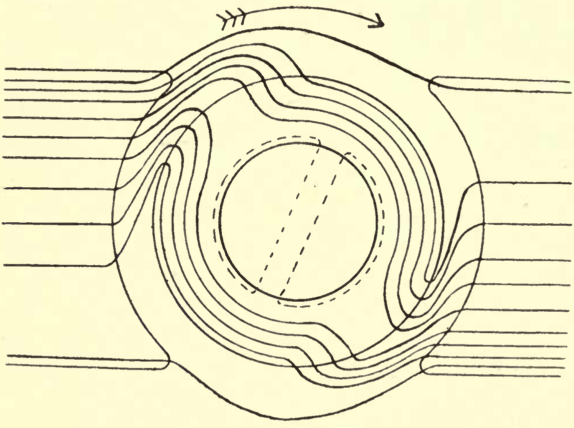

FIG. 30.

brushes while actively cutting the lines of force, and considerable sparking at the brushes will result.

Eddy Currents.—Another very important reaction which occurs when the dynamo is working, is the production of *eddy currents* in different parts of the machine. This term is applied to the currents which are always produced when a solid metallic mass is rotated in a magnetic field, or is subjected to the action of a magnetic field which is undergoing change in its intensity or strength, for the reason that the currents generated always tend to flow in more or less circular paths. When produced in large solid metallic masses, the strength to which these eddy currents attain is frequently very considerable, owing to the low electrical resistance of the masses in which they flow; and in addition to consuming a large amount of energy, they frequently occasion a large and dangerous rise in the temperature. The cores of armatures being made of iron, are, unless suitably constructed, subject to the detrimental influence of these eddy currents, as is also the case with the conductors wound upon the core if these are of large cross-sectional area. To entirely prevent the generation of these eddy currents is impossible; they can, however, be prevented attaining any considerable strength, by suitably interposing resistance in their path. With this object, the cores and conductors of armatures are *laminated*, or subdivided into a number of small parts, each of which is electrically insulated from the other by some insulating material.

CHAPTER V.

ARMATURES IN PRACTICE.

HAVING in the preceding chapter considered the principles and action of the two types of armatures at present in most extensive use, it now remains to describe briefly in detail the practical construction of such armatures.

Armature Cores.—The cores of all practical armatures are now invariably *laminated*, or constructed of iron wire, ribbon, or discs. This method of construction is adopted in order to minimise as far as possible the generation of eddy currents, which otherwise, if the core were constructed of solid iron, would attain considerable and even dangerous proportions.

Disc Armature Cores.—The cores of all large armatures of the ring and drum types are as a rule built up of iron discs; when small, however, they are frequently constructed of iron wire. The discs are stamped out of thin sheet-iron of about $\frac{1}{32}$ of an inch in thickness, with a hole in the centre of each disc sufficiently large to accommodate the shaft and driving spokes, and also the conductors in the case of ring armatures. In most cases notches or keyways are stamped on the inner periphery of the discs (as in Fig. 31), to fit over the driving spokes, or over feathers running along the length of the shaft. These thin discs are then separated by some insulating material, and clamped between two thicker end discs or flanges so as to form a solid cylinder or drum. In this mode of construction the iron core, whilst carrying out its primary function of conducting the lines of force from pole to pole of the field magnet, interposes such considerable resistance in the path of the eddy currents as to effectually prevent these latter attaining any appreciable strength.

FIG. 31.

Toothed Cores.—Ring and drum armature cores are frequently constructed with deep channels or grooves in the outer periphery, in which the conductors are wound. The projections or teeth in this method of construction present an excellent means of driving and protecting the conductors, but the difficulty of insulating the latter from the core is increased by their use, and they also have a tendency to produce eddy currents in the pole pieces of the field magnets, causing a heating of the latter. The latter disadvantage can, however, be obviated to a great extent by making the teeth very narrow and numerous. When the

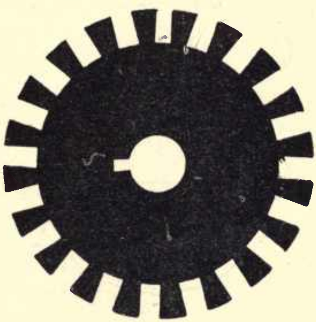

FIG. 32.

toothed type of core is used, the discs are stamped out with projections or teeth at regular intervals around the periphery (Fig. 32), and clamped together so that the projections and interspaces form continuous ridges and channels around the periphery, along the length of the core, for the reception of the conductors.

Insulation of Core Discs.—In order to prevent the circulation of any considerable eddy currents within the core, the core discs are electrically insulated from one another. Owing, however, to the very low E.M.F. of the currents, the insulation required is very slight; some manufacturers separate each disc by a paper or mica disc of similar form to the iron disc; others merely varnish the discs with shellac or other varnish, and this slight insulation is found to be quite effective in the prevention of dangerous eddy currents.

Driving Spokes and Spiders.—In most armatures the driving spoke or spider wheel serves a double

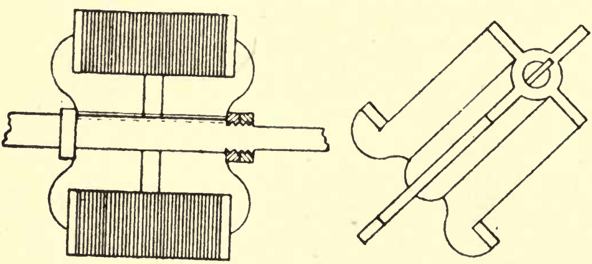

FIG. 33.

purpose, (*a*) to firmly clamp the core discs together so as to form a solid core; (*b*) to firmly fix the core to the shaft. The method generally followed in clamping and holding ring armature cores is illustrated in Fig. 33. The spiders or stars are of gun-metal, and are two in number, each having four arms or spokes, with end projections against which the thicker end flanges fit. The core discs are stamped with four notches or slots on their inner periphery, and the arms of the spiders engage in these and prevent the discs turning. The spiders fit over the shaft, and are prevented from turning thereon by feathers. One of the spiders fits against a shoulder turned upon the shaft, and the core discs are strongly compressed between this and the other spider by means of lock-

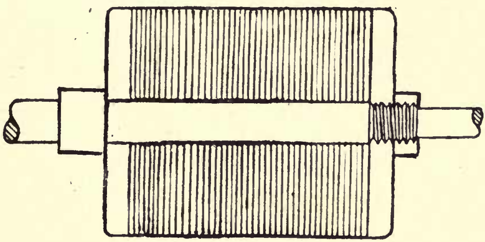

FIG. 34.

nuts turning upon threads cut upon the shaft. All well-constructed ring armatures are now provided with these driving spokes or spiders, but they are frequently dispensed with in drum armatures, the core discs themselves being keyed on to the shaft. In such cases the discs are clamped between two end plates, one of which is secured by a shoulder turned upon the shaft, and the other by a screw-nut and lock-nut, as shown in Fig. 34.

Ventilation of Armatures.—The cores of all armatures are liable to become heated through the generation of eddy currents, the transmission of the heat from the conductors, and other causes. In small armatures no special means are taken to get rid of this heat, the relatively large amount of surface exposed, and the high initial velocity of such armatures, being found sufficient to prevent any dangerous rise of temperature. In the case of large armatures, however, some means of ventilation must be adopted, otherwise the armature will heat up to a dangerous extent. The method generally followed in such armatures is to cause air currents to circulate among the conductors and in the interior of the core. For this purpose the conductors are wound with air spaces between them, and cooling gaps are frequently left at intervals between the core discs. When the core discs are fixed direct on to the shaft, they are frequently punched with holes, so that when assembled upon the shaft continuous ventilating apertures are formed in the core, through which the air circulates and carries off any excess heat.

Drivers.—When a current is flowing in the conductors of an armature revolving in a magnetic field, the magnetic attractions and repulsions set up have a tendency to displace the conductors and drag them out of their places around the core. Means must therefore be taken to resist this injurious action, and to fix the conductors immovably to the core. In small armatures, where the displacing forces are relatively very small, simple friction is generally relied on to effect the purpose, the grip of the conductors upon the core, reinforced by the pressure of the binding wires, being found quite sufficient to hold the conductors in their places. In the case of large armatures, however, where the displacing force upon each conductor may amount to many pounds, some more positive means of driving the conductors must be adopted; with this object the cores of such armatures are generally provided with *drivers* of metal or other substance. These drivers are arranged and fixed to the core in a variety of ways; in some cases they consist of steel or other metal pins insulated with vulcanised fibre, and screwed or driven into the core for a certain distance, so that they stand up level with the conductors; or strips of wood or fibre are arranged longitudinally along the surface of the core, being screwed to the latter, or let into grooves milled or planed in the surface of the core. Either of these forms of drivers, in conjunction with the binding wires, forms a most effective means of driving the conductors, and entirely prevent any slip of the latter over the core.

Conductors.—In all practical armatures the conductors are invariably of copper, although iron has been suggested for the purpose at different times. For small currents they are generally of circular section, and wound in two or more layers upon the surface of the core; but for heavy currents they are always of rectangular or trapezoidal section, in order to economise the space around the periphery of the armature to the greatest extent. In both cases they are insulated with silk, or a double layer of cotton braided on and varnished with shellac or rubber varnish.

Laminated Conductors.—When the cross sectional area of the active conductors of an armature exceed a certain limit, there is great liability for eddy currents to be generated within them. To prevent this occurring, many makers employ laminated conductors, or conductors formed of stranded copper wires. In Messrs Crompton's patent stranded armature conductors, the separate strands are varnished or oxidised, or otherwise lightly insulated from each other, and then compressed into a bar of

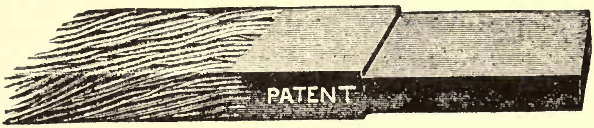

FIG. 35.

rectangular or trapezoidal section, as shown in Fig. 35. These stranded armature bars are very effectual in the prevention of eddy currents and the accompanying waste of energy, Messrs Crompton having found that by their use in large armatures the efficiency of the dynamos is increased as much as 3 or 4 per cent.

Connectors.—When the size or section of the conductors of drum armatures exceeds a certain limit, considerable difficulty is experienced in the winding, in bending and arranging the conductors over the ends of the drum or core, and in such armatures *connectors* are therefore generally employed. These connectors, as their name implies, are used for the purpose of connecting the conductors situated at opposite sides of the core together. They consist of flexible strips or stampings of thin sheet-copper, insulated with tape or other suitable material, and arranged at either ends of the core. They take a variety of forms or shapes, but the arrangements due to Hopkinson and Kapp appear to be most extensively used in practice. Dr Hopkinson's method of arranging the connectors is shown in Fig. 36. The conductors of the armature are rectangular in section, and project over the ends of the core for a longer or shorter distance alternately, as shown in the side view Fig. 36. Two commutator-like structures A A, consisting of a number of copper segments S S, insulated from each other, and fixed upon a wooden drum, are arranged at either end of the core, and into saw-cuts

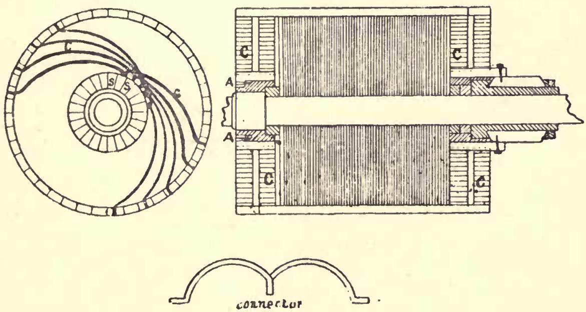

FIG. 36

in each of these segments are soldered two thin strips of copper, C C, insulated with tape. These thin copper strips are bent in opposite directions (as shown in end view Fig. 36), and their ends are soldered into the long and short armature conductors situated at approximately opposite ends of a diameter of the core, as shown in the end view of Fig. 36. At the commutator end of the armature the copper segments are continued outwards, and connected to the commutator segments, as represented in the side view Fig. 36. In the system due to Mr Kapp, each of the connectors consists of a stamping of thin sheet-copper of semi-circular form, shown in Fig. 37, with a tag at either end. The connectors are insulated with varnished tape, and are built up on a cast-iron bobbin or

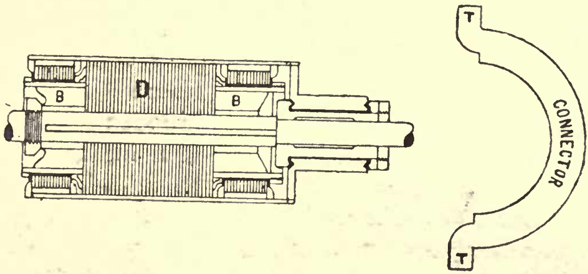

FIG. 37.

clamp, B B, fixed at either end of the armature core D. The conductors are arranged to project over the ends of the core for a longer and shorter distance alternately, as in the Hopkinson armature, and the tags of each connector are bent over, at right angles to the connector but in opposite directions, and soldered to the projecting ends of the long and short armature bars situated at approximately opposite ends of a diameter. At the commutator end of the armature the long bars are extended for a greater distance over the end of the core, and soldered to the lugs of the commutator, as shown in sectional view of armature Fig. 37. A complete drum armature, fitted with Kapp end connectors, is depicted in Fig. 38. In addition to the better mechanical construction, and ease in winding the conductors, secured by their use, these connectors offer two other important advantages, viz., (*a*) the end connectors can be much better insulated than is the case with the wires passing over the ends of wire wound armatures, and as conductors at great differences of potential are not brought near to each other, short circuiting between adjacent conductors is greatly minimised; (*b*) the repair of the armature

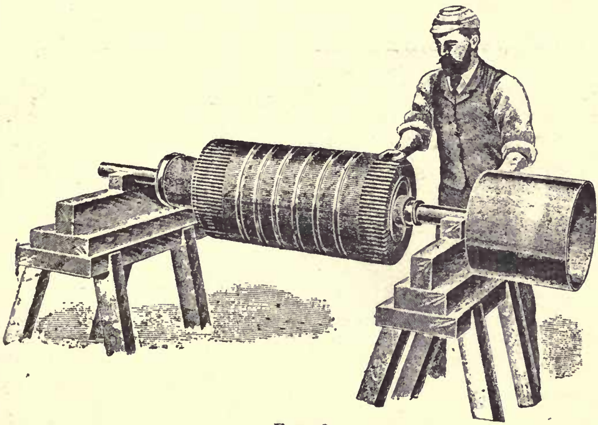

Fig. 38.

is also greatly facilitated, for owing to the conductors and connectors being entirely distinct, if a conductor becomes damaged at any time it can be unsoldered from its connectors and a new conductor soldered into its place, without disconnecting or removing any other portion of the winding.

Binding Wires.—The conductors of an armature, in addition to being subjected to the peripheral drag exerted by the magnetic field, are also subjected to the influence of the centrifugal force developed by the rotation of the armature. As most armatures are driven at a high peripheral speed, this force is often considerable; therefore, in order to counteract the tendency of the conductors to be driven off by the action of this force, they are bound down to the core by means of bands of binding wires. These binding wires are usually of steel, hard brass, or phosphor-bronze, wound under tension upon bands of vulcanised fibre and mica, fixed upon the periphery of the armature, and soldered at intervals to obviate flying asunder.

The Commutator.—The commutator as a rule is built up separately from the armature, and consists of a number of segmental bars of brass, copper, or phosphor-bronze, insulated from each other, and fixed in a clamping sleeve which slides over and is made fast to the shaft.

Construction of Commutators.—The construction of commutators is illustrated by the example given

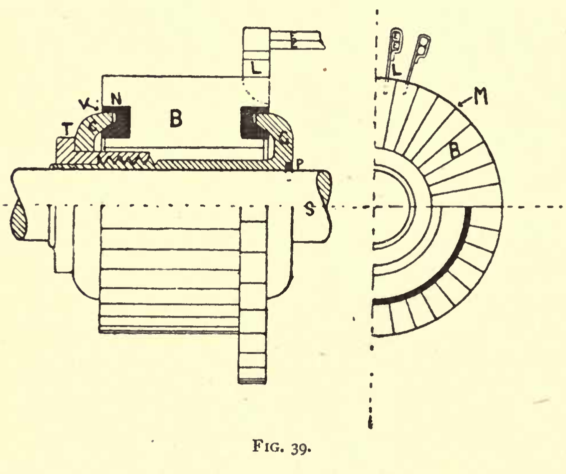

FIG. 39.

in Fig. 39, which represents the Kapp commutator. Two views of this commutator are given, the upper half in each case being shown in section. The segments B are of hard drawn copper, insulated from each other by slips of mica, M. Square clamping notches, N, are turned in the ends of the assembled bars, into which fit grooved rings of hard vulcanised fibre. These rings have a coned surface, and are cut into three segments so as to permit of slight contraction. A gun-metal bush or sleeve, G, having a cone turned upon one end, slides over the shaft S, and is prevented from turning thereon by the pin P. A tubular nut, T, screws on to one end of the bush, and over this slides a loose coned collar, C. The two gun-metal cones fit into the grooves in the fibre rings, and when forced together by the screw-nut T on the end of the sleeve, binds the whole of the segments firmly together. The electrical connection of the segments of the commutator to the coils of the armature is effected by means of the lugs L. These are made of thin strip copper, of a suitable length, to connect the ends of the armature coils to the segments of the commutator. A saw-cut is made in one end of each of the segments, and one end of the lug is soldered or sweated into this, the other end being bent round and soldered to the projecting ends, E, of the armature coils, as represented in the sectional view of the commutator.

Brushes.—The brushes bear upon the commutator, and make sliding contact with the armature and working circuits. It is needful that they should have a certain amount of flexibility, in order that they may accommodate themselves to any little inequality which may occur upon the surface of the commutator, and also to avoid cutting or scoring the latter; with these objects, they are usually made of copper or brass gauze, wire, or flexible strip.

Gauze Brushes.—This type of brush is now very extensively used, owing to its great flexibility and soft and yielding nature, resulting in decreased wear of the commutator. It is made up of a sheet of copper gauze, folded round several times, with the wires running in an oblique direction, so as to form a

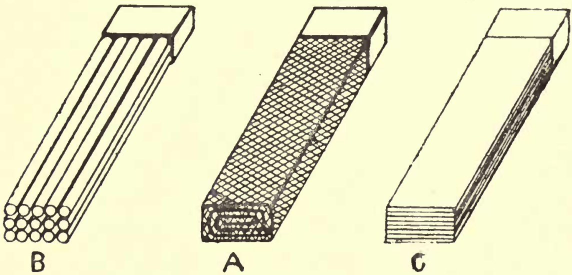

FIG. 40.

solid flat strip of from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch in thickness, as shown at A, Fig. 40, the thickness increasing with the volume of the current to be collected. The object of folding the gauze up with the wires running in an oblique direction is to prevent the ends of the brushes fraying or threading out, which would be the case if the gauze was folded up in any other manner.

Wire Brushes.—This brush (B, Fig. 40), which was much used previous to the invention of the gauze brush, is made up of a bundle of brass or copper wires, laid side by side and soldered together at one end. Being harder than the gauze brush, it is more liable to cut or score the commutator, and it is also more troublesome to trim.

Strip Brush.—This is probably the simplest form of brush, but is not very extensively used owing to its lack of flexibility. It consists of a number of strips of copper or brass, laid one upon the other and soldered at one end, as in C, Fig. 40.

Carbon Brushes.—When metallic brushes are used upon the commutators of high tension machines, they frequently give rise to excessive sparking, and also heating of the armature, the metallic dust given off appearing to lodge between the segments of the commutator, thus partially short circuiting the armature. To obviate this, carbon brushes are frequently used on such dynamos, this substance being found very effectual in the prevention of sparking. The brushes are usually in the form of oblong blocks placed "butt" end on the commutator, and fed forward as they wear away by means of a spring holder.

Brush Holders.—In order to secure sparkless collection of the current, and to prevent undue wear

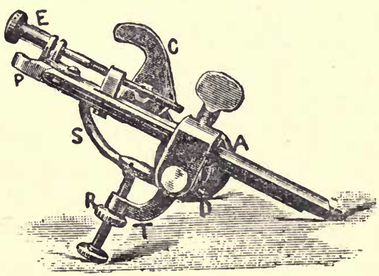

FIG. 41.

of the commutator, it is needful that the pressure of the brushes upon the latter should be capable of being adjusted to meet requirements; it is also needful that they should be capable of being fed forward as required, as they wear away, and that they be furnished with a movement to permit of the brushes being raised from contact with the commutator when necessary. Each maker has his own particular arrangement for giving these essential motions to the brushes, and, as may be conceived, they frequently differ widely. The requirements of a good brush-holder are met in a very efficient manner in the Newton-Hawkins patent brush-holder, illustrated in Fig. 41. A pair of the brush-holders mounted complete on the arms of the rocker is shown in Fig. 42. The holder consists of two parts—the tail-piece T fixed immovably to the arm of the brush-rocker by means of the small set-screw D, and the movable brush clamp A capable of revolving through a small angle on the fixed tail-piece. Contact pressure of the brush is produced by the laminated plate-spring S (shown more clearly in Fig. 42), the tension of which is adjusted by means of a regulating screw and lock-nut R. The brush is held up from contact with the commutator by means of the hold-off catch C, composed of a vulcanised fibre cam turning on a pivot. The brush can be fed

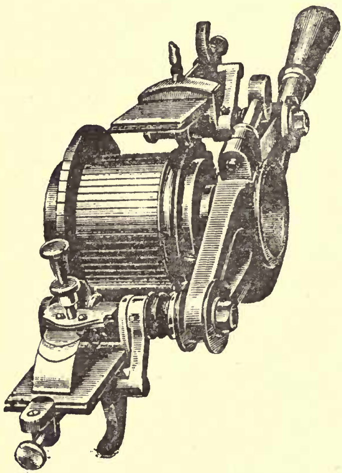

FIG. 42.

forward in the holder, or drawn back and adjusted, while the machine is running, by unscrewing the clamping-screw H and adjusting the regulating-screw E. The brush is connected to the terminals of the machine by means of a flexible "lead," bolted to the point P of the holder. In all well-designed dynamos not less than two brushes are used on each side of the commutator ; this allows of either brush being removed, and examined and trimmed, while the machine is running. It also allows of the brushes being adjusted upon the commutator independently of each other, any uneven wear of the commutator being thus prevented, and better contact made.

Brush Rockers.—As previously mentioned, when a dynamo is working, the neutral points, or the points upon the commutator where sparkless collection of the current can be made, vary in position as the load upon the dynamos varies, moving round in the direction of rotation as the load increases, and *vice versa.* It is necessary therefore, in order to avoid sparking, to shift the brushes bodily upon the commutator from time to time, without in any way altering the adjustments of the brush-holder springs or breaking the working circuit. To enable this to be effected the brushes with their holders are, in ordinary bi-polar dynamos, usually fixed upon a "rocker" or "yoke." Fig. 43 illustrates the form of rocker commonly used. It is of cast-iron or gun-metal, made in two pieces and bolted together. The central aperture is turned out to fit into a groove turned in one end of the bearing next to the commutator, and the rocker, when rotated by means of the handle A into the correct position for the brushes upon the commutator, is clamped in position by the clamping-screw S. Through holes at opposite ends of the bar project two gun-metal spindles, M M, upon which the brush-holders are

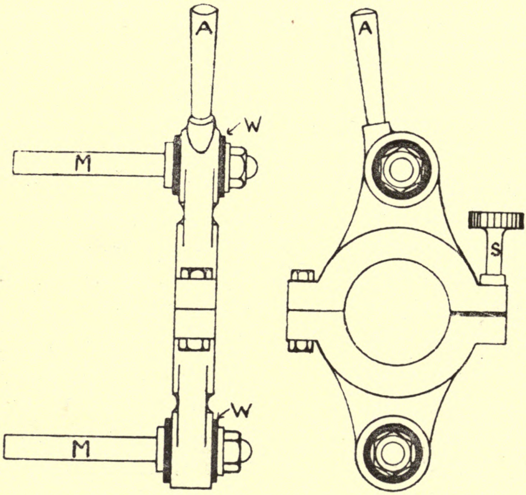

FIG. 43.

firmly fixed by the set-screws (D, Fig. 41). These spindles are entirely insulated from the rocker bar and from each other by the vulcanised fibre bushes and washers W W.

CHAPTER VI.

FIELD MAGNETS.

THE field magnet, the function of which is to produce an intense magnetic field within which the armature revolves, may be either a permanent magnet or an electro magnet. Electro magnets, however, possess such a number of important advantages over permanent magnets, that they are now invariably used in all machines intended for practical work. The chiefest advantages of the electro magnet, as compared with the permanent magnet, lies in the power of regulating the strength of the magnetic field produced by the former, by suitably adjusting the strength of the magnetising current flowing through its coils, and also in the greater magnetic effect obtained, weight for weight, from the electro magnet over the permanent magnet.

Excitation of Field Magnets.—The field magnets of a dynamo may be excited, either by the current furnished by an independent dynamo or battery, in which case the machine is said to be "*separately excited*," or by the current generated in the armature of the machine of which the field magnet forms part, when the machine is said to be *self-excited.*

Self-Excitation.—The latter type of machine depends for its action upon the presence of residual magnetism in its field magnet. Owing to this residual magnetism, a weak magnetic field is always present between the pole pieces of a field magnet; hence, when the armature is rotated in the armature chamber, its conductors cut the lines of force contained in this magnetic field, and a small E.M.F. is set up in the armature in consequence. The ends of the magnetising coils being suitably connected to the brushes, if these latter are in contact with the commutator, and a closed circuit through the field magnet windings is formed, this small E.M.F. immediately sends a minute current through the exciting coils; this immediately increases the strength of the magnetic field, and as a consequence an increased E. M. F. is induced in the armature. This results in a stronger current being sent through the exciting coils, and the increase of magnetism which follows results in an increased E.M.F. in the armature. Thus the process goes on, until eventually, for a given speed of rotation of the armature, the E.M.F. reaches a maximum value, beyond which it will not increase without a further increase in the speed of rotation; the exciting current has then arrived at a constant value, and the magnetisation of the machine will remain at a constant strength, and maintain the E. M. F. so long as the armature rotates at its normal speed. If the armature ceases to revolve, the field magnets will of course be deprived of their exciting current, and will therefore lose their magnetism; the iron will, however, retain a sufficient amount of residual magnetism to again start the process when the machine is again started. In most cases an appreciable time elapses before the voltage arrives at its maximum value: in small dynamos, a few seconds generally suffices to fully excite the machine; in the case of large shunt dynamos, it may require a minute, or even five minutes in exceptional cases.

Classification of Dynamos. — The manner in which the coils of the field magnets are connected to the armatures of self-exciting machines gives rise to the following classification:—

(1) *Series Wound Dynamos.* In which the coils of the field magnet are connected in series with the armature and external circuit.

(2) *Shunt Wound Dynamos.* In which the coils of the field magnet form a shunt to the armature and external circuits, and, being composed of many turns of fine wire, absorb only a fraction of the total current.

(3) *Compound Wound Dynamos.* Wherein two coils are wound upon the field magnets, arranged in a combination of shunt and series: one coil being wound with a large number of turns of fine wire, and connected as a shunt to the armature; the other being composed of a few turns of thick wire, and connected in series with the armature.

Separately Excited Dynamos. — This type of machine is not so extensively used as the self-exciting type, owing principally to the fact that an independent dynamo or battery is necessary for exciting its field magnet. It finds its chiefest application in the electric transmission of power, and in charging accumulators, and in all cases where a high

E. M. F. is required with a varying current. The connections of this dynamo are shown in Fig. 44, where N S are the poles of an electro magnet, which is excited by the current generated by the independent dynamo or battery D. The armature A revolves in the space between the two pole pieces, and the two brushes B_1 B_2 press upon the com-

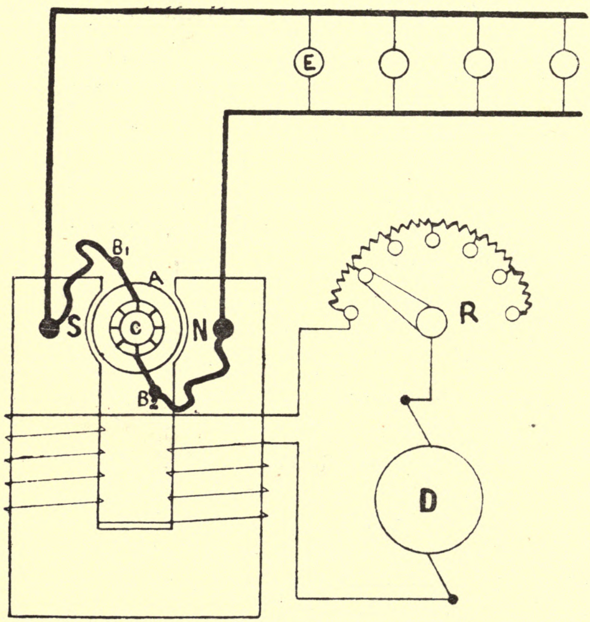

FIG. 44.

mutator C, and convey the current generated in the armature to the external circuit E. The E.M.F. and output of the dynamo is usually regulated by varying the strength of the magnetising current (produced by the dynamo or battery D) flowing in the coils of the field magnet by means of the hand-regulator R.

Series Dynamos.—The manner in which the connections of the series wound dynamo are arranged is shown in Fig. 45. The coils of the field magnet are wound with a few turns of thick insulated wire,

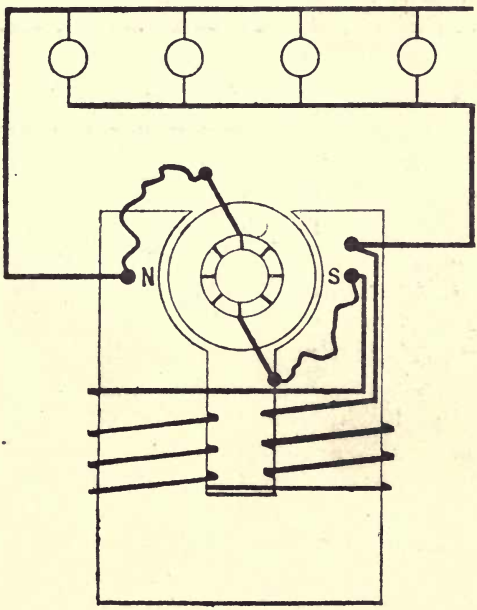

FIG. 45.

and being joined in series with the armature, the whole of the current generated in the latter passes direct through them, and thence to the external circuit. The current in passing through the coils of the field magnet energises the latter, and creates a magnetic field between the two poles N S, in which the armature revolves. A little consideration will show that the strength of this magnetic field, and therefore the E. M. F. of the machine, will vary in direct proportion to the current flowing in the external circuit, since the current flowing in the external circuit is also the magnetising current. If the external current is "open," no current will flow therein, and therefore the field magnets will be unexcited, and the only magnetic field will be that due to the residual magnetism of the field magnets; the E. M. F. of the machine will, therefore, be practically *nil.* If, on the other hand, the external circuit is closed, so as to offer a minimum resistance, or "short circuited," the field magnet will be excited to the greatest extent, and the E. M. F., and current flowing in the external circuit, will be approximately a maximum.

Characteristic Curves.—The behaviour of series wound and other dynamos can best be studied graphically by means of "*characteristic curves.*" As Prof. S. P. Thompson remarks,* "the characteristic curve stands to the dynamo in a relation very similar to that in which the indicator-diagram stands to the steam-engine. As the mechanical engineer by looking at the indicator-diagram of a steam-engine can at once form an idea of the qualities of the engine, so the electrical engineer by looking at the characteristic of the dynamo can judge of the qualities and performance of the dynamo." The shape or form of the characteristic curve differs, of course, with the type of dynamo

* "Dynamo Electric Machinery," Spon, 1892.

whose qualities it represents, the form of the characteristic of a series dynamo being entirely different from that of a shunt or compound wound machine. The characteristic of a series dynamo is given in Fig. 46. The abscissae measured horizontally represent the number of amperes flowing in the circuit; and the ordinates, shown vertically, the corresponding value of the terminal E.M.F.,—the armature rotating

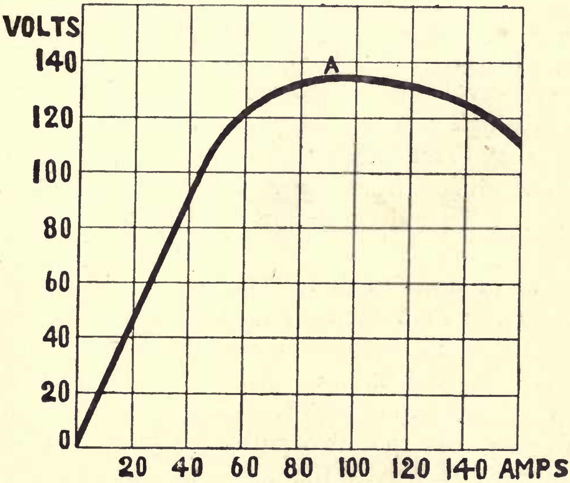

FIG. 46.

at a constant speed. It will be noticed that the curve does not begin exactly at the point O, but a little way up the vertical line; this indicates the existence of a small E.M.F. before current is taken from the machine, and is due to the residual magnetism of the field magnets. As current is taken from the machine, the magnetisation of the field magnets increases at first, very rapidly with the current; and therefore the electro-motive force increases also, giving the first portion of the curve. After a time, however, the cores of the field magnet become saturated ; the curve then attains a maximum height, at A ; and as more current is taken from the armature, the de-magnetising action of the latter, and the fall of pressure over the resistances of the machine, increase so rapidly, that the E. M. F. at the terminals of the machine is decreased, as indicated by the curve bending downwards. Series wound dynamos are chiefly used for lighting arc lamps in series, and for the electric transmission of power over long distances, and for other purposes where a high potential is required.

Shunt Wound Dynamos.—The shunt wound dynamo differs from the series wound machine, in that an independent circuit is used for exciting its field magnet. This circuit is composed of a large number of turns of fine insulated copper wire, which are wound round the field magnet and connected to the brushes, so as to form a shunt or "by pass" to the brushes and external circuit. Fig. 47 shows the connections of the shunt wound dynamo, from which it will be seen that two paths are presented to the current as it leaves the armature, between which it divides in the inverse ratio of the resistance; whilst one part of the current flows through the magnetising coils, the other portion flows through the external circuit. In all well designed shunt dynamos, the resistance of the shunt circuit is always very great, as compared with the resistance of the armature and external circuit, and the strength of the current flowing in the shunt coils rarely exceeds 12 amperes in even the largest machines.

Characteristic of Shunt Dynamo.—The general form of the characteristic curve obtained from a shunt wound dynamo is illustrated in Fig. 48. The ordinates shown vertically represent the volts at the terminals of the machine, the abscissae the amperes flowing in the external circuit, with the

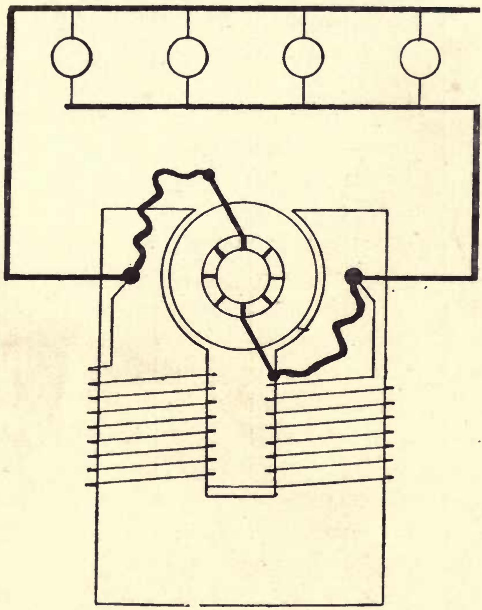

FIG. 47.

armature running at a constant speed. Starting with the external circuit open, the only current flowing is that in the shunt coils of the field magnet, which latter is consequently magnetised to the greatest extent, and therefore the E. M. F. at the terminals of the machine is at a maximum value. When the external circuit is closed, as current is taken from the armature, the loss of volts over the resistance of the latter increases

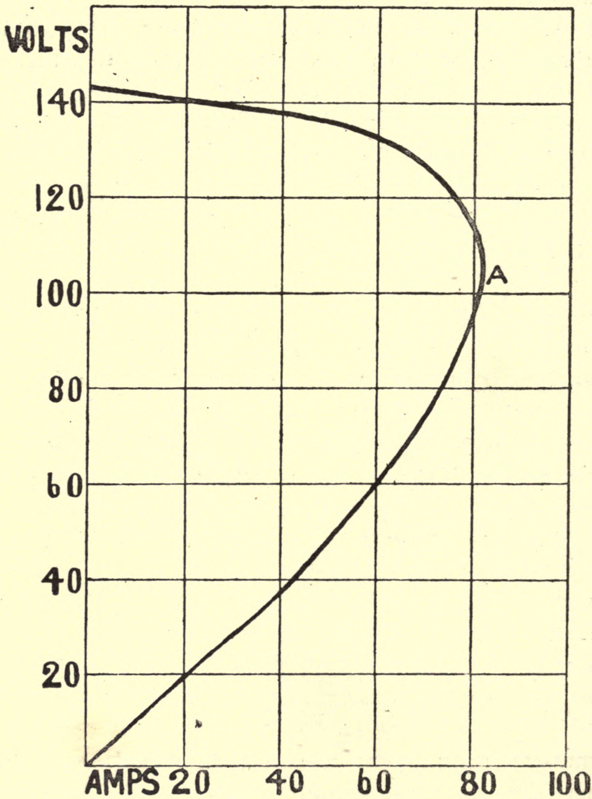

FIG. 48.

as more and more current is taken from the machine. Hence the pressure at the brushes is reduced, and this resulting in a decrease of the magnetising current, the curve begins to fall gradually downwards, until when the point A is reached the voltage has been so far reduced that the machine commences to de-magnetise or "build down," and the voltage then runs down to zero. The shunt dynamo is therefore only capable of supplying a definite maximum current, beyond which, if the resistance of the external circuit is still further reduced, the machine will de-magnetise, and cease to generate current at all. The behaviour of the shunt dynamo is thus in many respects the reverse of the series wound machine: in the latter, the E. M. F. is greatest when the current flowing in the external circuit is a maximum; in the former, the E. M. F. is a minimum under like circumstances. Owing to its non-liability to reversal of polarity, the shunt wound dynamo is extensively used for charging accumulators, and for electrolytic and electro-metallurgical work, and also in central stations for the supply of electrical energy.

Compound Wound Dynamos.—In practice, electric lamps, motors, and other applications of electrical power, are constructed for a definite pressure and current, which must be maintained constant if the appliances are to work efficiently. In incandescent lighting, where the lamps are arranged in parallel, a constant voltage must be maintained between the terminals of the lamps, no matter how few or how many are burning. Under such circumstances it will be evident that simple shunt or series wound machines would be quite unsuitable, for the pressure would vary with every variation of the current as the lamps are switched into or out of circuit. For the purpose of automatically maintaining a constant pressure in incandescent lighting, the compound wound dynamo (Fig. 49) is now generally employed. The field magnet of this dynamo is wound with two sets of coils, one set being connected in series, and the other set in parallel, with the armature and

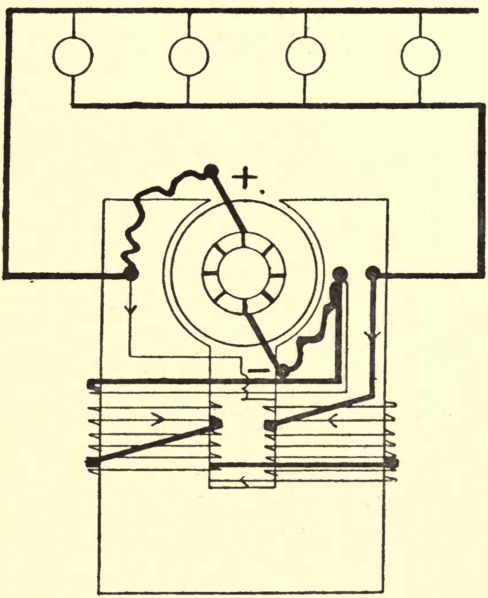

FIG. 49.

external circuits. The machine is in reality a combination of the shunt and series wound machines, and from what has been already stated regarding the behaviour of these types of dynamos, the action of the compound dynamo will be apparent. When the external circuit is open, and no load is therefore on the dynamo, the shunt coil will maintain the E.M.F. at the terminals at the correct value; as the load increases, the fall of pressure at the terminals of

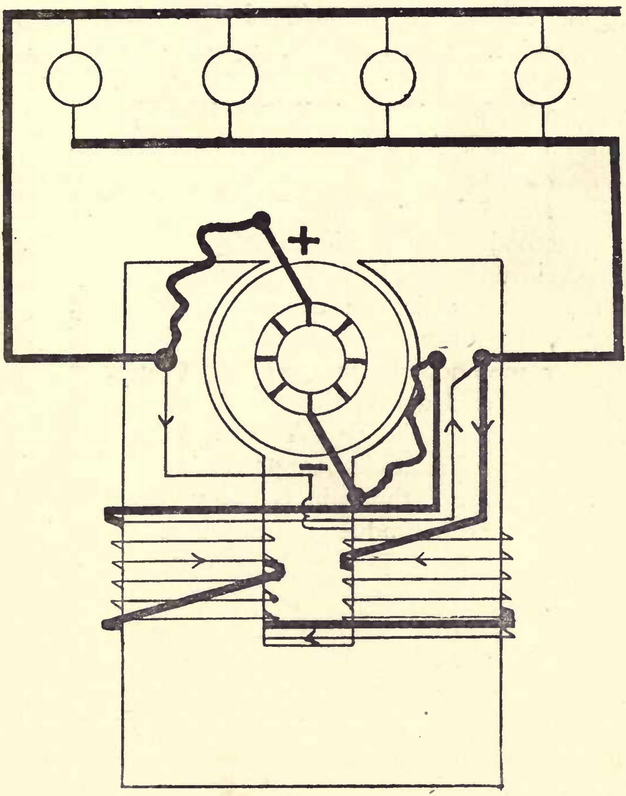

FIG. 50.

the machine, due to the loss of volts over the armature resistances, and the reduced current in the shunt coils, will be compensated by the increase of induced

E. M. F. in the armature, due to the increase of exciting power furnished by the series coils; and if the series and shunt coils are correctly proportioned, the E. M. F. at the terminals of the dynamo will be maintained constant throughout the entire range of the machine. This is, however, only true when the dynamo is run at the speed for which it was designed; at any other speed the windings will not compensate each other, and the voltage will not remain constant with a varying load.

Short and Long Shunt Compound Winding.—The method of connecting the coils of compound dynamos, represented in Fig. 49, in which the ends of the shunt coils are connected directly to the brushes, is known as the *short shunt winding*. Another method, shown in Fig. 50, in which the shunt is placed across the terminals, is known as the *long shunt winding*. Theoretically, the latter method is preferable, as being the most efficient; in practice, however, the gain is not very appreciable, and the former method is generally used.

CHAPTER VII.

FIELD MAGNETS IN PRACTICE.

WHILST the construction of the armatures of different dynamos may be said to be very much the same, differing in small details only, and being confined to two types, viz., the ring and drum respectively, the construction of the field magnets varies greatly, almost every manufacturer having his own particular form and arrangement. This great variety in the form of the field magnets of different dynamos, is due in a large measure to considerations of economy involved in the manufacture by different makers, and also, to a less extent, to the different conditions under which a machine is required to work. For example, it is sometimes necessary for a machine to give a maximum of output with a minimum of weight, and under such circumstances the field magnet is constructed wholly of wrought-iron, and this necessarily entails an entirely different method of construction and arrangement than if cast-iron were employed. Again, as a rule, the direct coupling of the armature to the engine-shaft involves a different form of field magnet than would be the case if the armature were belt driven.

Construction of Field Magnets.—Owing to difficulties of construction, and other considerations, field magnets are not in practice usually constructed out of a single piece of iron, but are usually built up of a combination of parts, and composed either wholly of wrought or cast iron, or of a combination of both. The construction of a typical field magnet is illustrated in Fig. 51, from which it will be seen that it may be divided into five parts, viz.:—the two limbs or cores M M, upon which the exciting coils C are wound; the two end portions P P, called the "pole pieces," which are bored out so as to form the "armature chamber" within which the armature revolves; and the yoke, Y, which serves to connect the two limbs together, and thus complete the magnetic circuit. The permeability of wrought-iron being very much greater than cast-iron, the portions M M of the field magnet, upon which the exciting coils are wound, are frequently constructed of this material; these portions are also usually constructed of a circular section, and thus the amount of wire required for exciting the field magnet is economised to the utmost extent. The pole pieces P P and the yoke Y are in many cases of cast-iron, bolted on to the wrought-iron limbs.

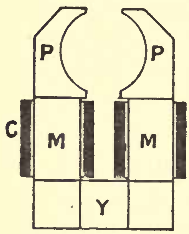

FIG. 51.

Forms of Field Magnets.—Although innumerable forms of field magnets have been devised, they can all be arranged into two groups, viz., those in which the poles are "salient," and those in which the poles are "consequent." A salient pole is the term applied to poles which are produced at the ends of a bar of iron, in distinction to consequent poles, which are produced in a continuous ring of iron.

Salient Pole Field Magnets.—The salient pole form of field magnet, being least costly to construct, is most frequently met with in practice.

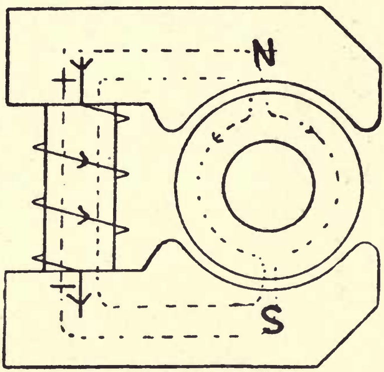

FIG. 52.

Fig. 52 shows its simplest form: in this arrangement only one magnetising coil is required, this being wound upon the yoke, which is usually of wrought-iron, let into and bolted to the cast-iron pole pieces N S. The paths and directions of the lines of force, with the magnetising current flowing in the direction shown, is indicated by the dotted arrow heads and lines. Another form of field magnet which is very extensively used, and in which two exciting coils are required, is shown in Fig. 53. In this type the limbs are usually of wrought-iron, of rectangular section, bolted to the bedplate of the machine, which therefore forms the yoke of the magnet. The magnetising coils are wound upon bobbins, which are slipped over the limbs, being held in place by the cast-iron "horns" C C, screwed on at the lower portion of the armature chamber.

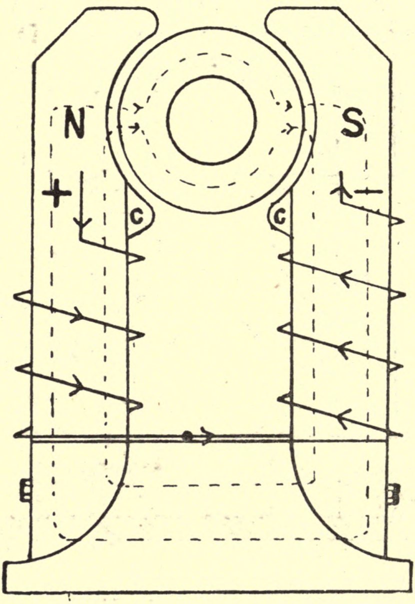

FIG. 53.

The form of field magnet illustrated in Fig. 53 is known as the "overtype"; when the armature is placed below the field coils and yoke, as represented in Fig. 54, the arrangement becomes the "undertype." This latter type is very extensively used in large dynamos, owing to the low centre of gravity of the revolving armature resulting in increased stability and freedom from vibration; it is also invariably employed when the armature is to be coupled direct to the engine crank-shaft. In most cases the whole of the field magnet is com-

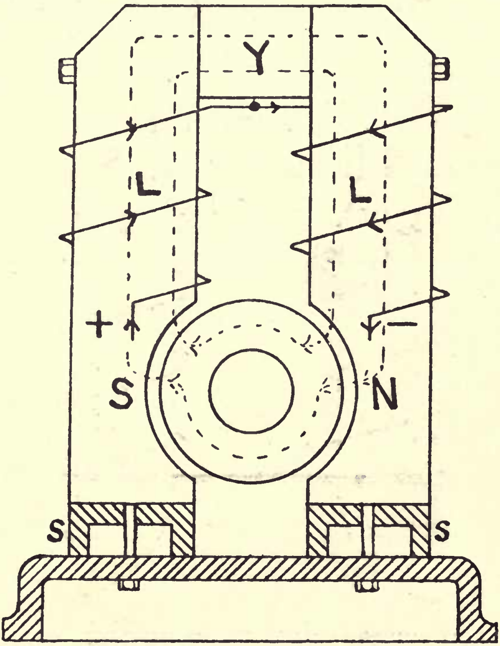

FIG. 54.

posed of wrought-iron, the two limbs being formed of rectangular slabs bolted to the yoke. As a rule, this class of field magnet is supported upon a bedplate of cast-iron, and therefore it is necessary to magnetically separate its pole pieces therefrom, otherwise they will be magnetically short circuited, or the lines of force will flow through the bedplate in place of passing through the armature core. To effect this the pole pieces are supported at a suitable distance from the bedplate by "footsteps," S S, or brackets of zinc, brass, or other non-magnetic substance.

Consequent Pole Field Magnets.—The two leading types of consequent pole field magnets are illustrated in Figs. 55 and 56. The paths and directions of the lines of force in the field and armature

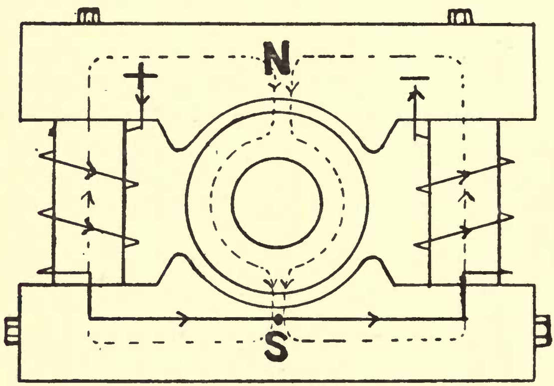

FIG. 55.

cores are indicated, as before, by the dotted arrowheads and lines. Fig. 55, which represents the "Manchester" type of field magnet, may be looked upon as a double magnet, the exciting coils being wound upon what may be regarded as the yokes of the magnets. The directions of the electric current flowing in the magnetising coils are such that two similar poles are produced in each pole piece. In Fig. 56 two similar poles are produced in each pole piece as in the "Manchester" type, but four exciting coils are necessary, these being wound upon the limbs

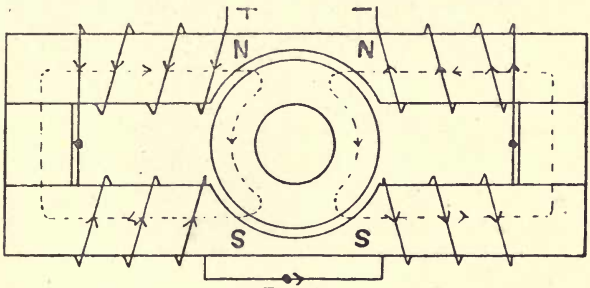

FIG. 56.

of the magnet, and connected up in a suitable manner to produce the requisite polarity in the pole pieces.

Multipolar Field Magnets.—These generally consist of 4, 6, 8, or more poles, arranged in alternate

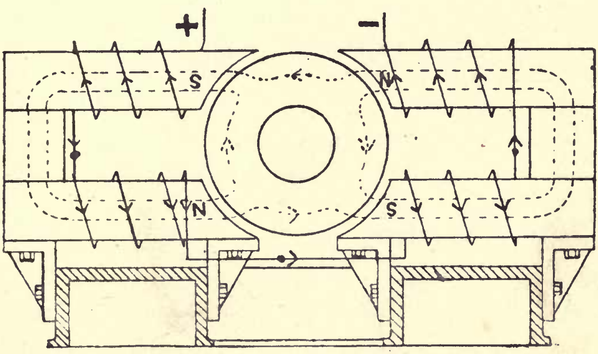

FIG. 57.

order around the armature. They may be arranged into two classes, according as the poles are salient or consequent poles. Fig. 57 illustrates the type of multipolar field magnet employed by Messrs. Crompton in their large dynamos. As will be seen, it consists of two separate and distinct magnets arranged horizontally, and supported by gun-metal brackets upon a cast-iron bedplate. The direction of the current in the magnetising coils is such that two north and two south poles are produced in alternate

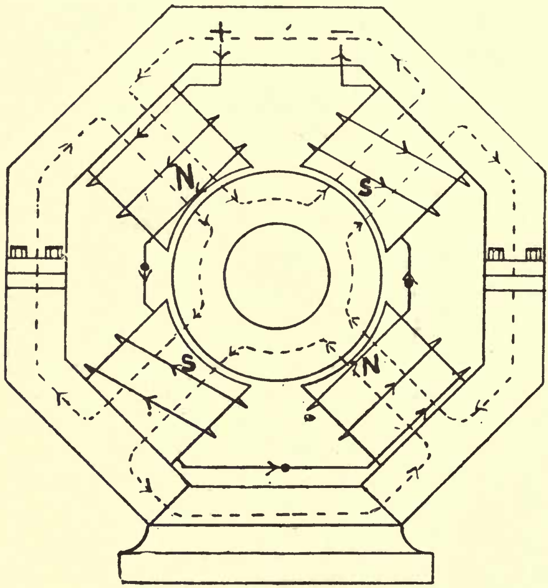

Fig. 58.

order around the armature. Fig. 58 represents a very commonly used type of multipolar field magnet; it consists of a ring of iron, having four pole pieces projecting inwardly, over which the exciting coils are slipped, the ring forming a common yoke for all the poles. As a rule, it is made in two portions, bolted together horizontally, so that the upper portion may be lifted off for examination of the armature. Fig. 59 is given as an example of the consequent pole type of multipolar field magnet. The magnet cores are of

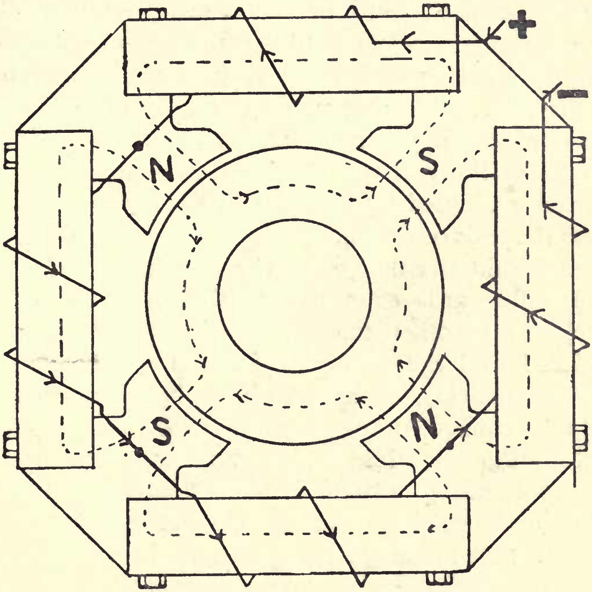

FIG. 59.

wrought-iron, bolted on to wrought-iron pole pieces, the magnetising coils being coupled up so as to produce consequent poles of alternate polarity around the armature.

Field Magnet Windings.—The insulated wires used for the excitation of the field magnets, not being subjected to any of the detrimental influences experienced by the armature conductors, are in most cases of solid copper. As a rule, the wires are wound upon insulated spools, which are afterwards slipped over the limbs of the magnet; in some cases, however, they are wound direct upon the core of the field magnet, this latter being previously insulated with vulcanised fibre or other insulating material. In general, the wires used for the exciting coils of shunt wound dynamos are very thin; hence when this is used for making connection to the terminals of the machine, it is very liable to break off near the flanges of the reel upon which it is wound. Several plans are adopted to prevent this occurring: in some cases the ends of the shunt coils are soldered to stouter wires within the flanges of the bobbins, these wires being afterwards connected to the terminals of the machine; in other cases, the ends of the coils are soldered to large terminals fixed upon the flanges of the bobbins, these terminals being afterwards suitably connected together by strips of copper.

Coupling up Field Magnet Coils.—In coupling up the exciting coils of dynamo field magnets, the primary essential is to so arrange the connections of the coils that the magnetising current flowing through them produces the requisite polarity in the respective pole pieces. In those field magnets provided with a single coil only (as in Fig. 52), no mistake can obviously be made; when two or more coils are used, however, it is possible to so arrange the connections that poles are produced in the yokes or other portions of salient pole field magnets; or in the case of consequent pole field magnets, the connections may even be so arranged that the coils neutralise each other, and no external field whatever is produced. The manner in which the coils of the various types of salient and consequent pole field magnets are coupled up, will be apparent from inspection of Figs. 52 to 59; but in order to still further facilitate the coupling up of field coils the following rule is given :—

Practical Rule for Coupling up Field Magnet Coils.—In coupling up the coils of either salient or consequent pole field magnet coils, assume each of the pole pieces to have a certain polarity (in bi-polar dynamos two poles only, a north and south pole respectively, are required; in multipolar dynamos the poles must be arranged in alternate order around the armature, the number of N and S poles being equal), then apply the rule given on page 21 to each of the coils, and ascertain the direction in which the magnetising current must flow in each in order to produce the assumed polarity in each of the pole pieces. Having marked these directions on the coils, the coils can be coupled up in either series or parallel according to requirements, so that the current flows in the necessary direction in each.

Connecting up Dynamos.—The manner in which the connections of the field magnet coils, and brushes, and terminals, are connected to one another, depends entirely upon the class of dynamo. The field magnet shunt coils of shunt and compound wound dynamos, are invariably arranged in series with one another, and then connected as a shunt to the brushes or terminals of the machine, as represented in Figs. 47, 49, and 50. The series coils of series and compound wound machines, are arranged either in series or in parallel with one another, according to circumstances, and the amount of current given by the machine, and then con-connected in series to the armature and external circuits upon the principle shown in Figs. 45, 49, and 50.

CHAPTER VIII.

REGULATING DYNAMOS.

In the practical operation of dynamos, some means of regulating their output are always needed, so that either the voltage or the current may be maintained at a constant value, or varied as required. The output of a dynamo may be regulated or varied by any of the following methods, or by a combination of the same:—(1) *Variation of speed of armature.* (2) *Variation of strength of magnetic field.* (3) *Variation of position of brushes on commutator.* (4) *Variation of resistance in dynamo circuit.* The application of these methods of regulation to the various classes of dynamos is considered in the succeeding paragraphs.

Regulating Separately Excited Dynamos.—As previously mentioned (p. 78), the voltage and output of this class of machine is most commonly governed by varying the strength of the magnetising current flowing through its field magnet coils. When the magnetising current is furnished by a battery or accumulator, this is effected either by means of a hard regulator or rheostat inserted in the exciting circuit (as represented in Fig. 44), or by varying the number of cells in circuit, this latter being the most economical plan. In most cases, however, a smaller dynamo is used for the purpose. In this case the strength of the magnetising current flowing in the coils of the main dynamo may be regulated by either of two methods :—(*a*) by means of a hand regulator inserted in the field circuit as before; or (*b*) by varying the voltage of the smaller exciting dynamo. This latter may be effected either by varying the speed of the armature, or by varying the strength of the magnetic field, by regulating the strength of the magnetising current flowing in the field coils by means of a hand regulator. When several separately excited dynamos are running together, it is a common practice to employ a smaller exciting dynamo for the exclusive purpose of supplying the magnetising current required for the field magnets of the several dynamos. The system of regulation then adopted depends upon whether the dynamos are supplying a common circuit, or running in parallel, or supplying independent circuits. The conditions of working in the former case require that the voltage of all the machines shall be varied simultaneously, and therefore the method of regulation, by varying the voltage of the smaller exciting dynamo, may be used with advantage. In the latter case, however, since each machine supplies an independent circuit, the voltages of which may vary greatly, such a method is obviously not applicable, for any variation of current will affect all the dynamos in common. It is therefore usual in such cases to provide the field circuit of each individual dynamo with a hand regulator, so that its pressure may be adjusted independently of the others.

Hand Regulators.—These, when applied to the regulation of dynamos, consist of multiple contact switches, so arranged that either the resistance of the field magnet circuit may be varied, by inserting or removing resistance in series with the latter, or one or more of the exciting coils may be cut into or out of circuit, or short circuited. When arranged for performing the former operation, the regulator is usually combined with a set of resistance coils, a combination of this description being illustrated in Fig. 60. It consists of two cast-iron end frames, rigidly connected together by means of two iron rods bolted into the ends of the frames. The two end frames are hollow, and each contain a slate slab, securely fixed in place by means of screws or bolts passing through the slabs, and screwing into the iron frames. The projecting edges of the slate slabs are provided with a number of brass studs or bolts, on to which are fixed the ends of spiral coils of German silver, platinoid, or iron wire. These spiral coils are all joined in series, being formed of a continuous length of wire, which passes up and down between the slate slabs. The connections of the spiral coils to the external circuit are made by means of two terminals, and a number of contacts fixed in the slate slab, in the bottom end frame. The terminal shown on the left of the figure is connected to the extreme left

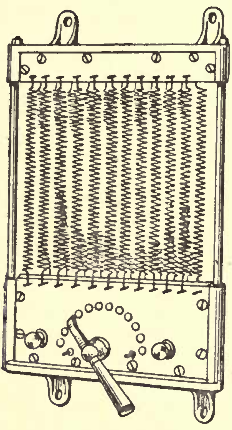

FIG. 60.

hand spiral coil, the terminal on the right being connected to the lever of the multiple contact switch or regulator, shown at the bottom of the figure. This is composed of twelve contacts, each contact being electrically connected to the bottom junction of a spiral coil. By altering the position of the lever of the regulator the coils can be cut in or out of circuit, and the resistance varied, as may be required. When the regulator is arranged for performing the latter operation, the switch is not combined with a resistance, but the exciting coils of the field magnets are divided up into groups, and the ends are connected to the contacts or terminals in place of the resistance coils, so that by varying the position of the lever each of the exciting coils may be cut into or out of circuit, and the strength of the magnetic field adjusted accordingly.

Regulating Series Dynamos.—The series dynamo is ordinarily used for operating series arc lamp circuits, and for the electric transmission of power, its regulation being effected by any of the following methods :—

(1) *Variation of strength of magnetic field.*

(2) *Variation of speed of armature.*

(3) *Variation of position of brushes on commutator.*

(1.) **Regulation by Variation of Strength of Magnetic Field.**—Although theoretically there are several different methods of varying the strength of the magnetic field of a series dynamo, in practice, the method of shunting the exciting current in the field coils is invariably followed. The essential principle of this method consists in establishing a shunt of variable resistance across the field coils, so that a portion of the armature current is shunted through the resistance, the remainder being used for exciting the field magnets. The strength of the magnetic field being proportional (within certain limits) to the strength of the magnetising current flowing in the exciting coils, it follows that the E. M. F. of the machine will vary in proportion to the resistance of the shunt. By reducing the resistance of the latter, a larger proportion of the total current will flow through it, and the strength of the current flowing in the field coils being thus reduced, the voltage of the machine will be reduced also, or *vice versa.* The alteration in the resistance of the shunt can be effected by hand, with the aid of a rheostat or hand regulator, similar in principle to that represented in Fig. 60. When used for this purpose, however, the hand regulator is usually so arranged that all the resistance coils can be cut out of circuit, and the field coils short-circuited, thus allowing of the voltage of the machine being adjusted from zero to the maximum value.

Automatic Regulation.—In cases where an approximately constant current is to be maintained in a circuit, as in series arc circuits, the adjustment of the resistance of the variable shunt is, as a rule, effected automatically by means of some electromagnetic device, actuated by solonoids placed in the main circuit.

Brush's Automatic Regulator.—The automatic regulator invented and used by Brush for the purpose of maintaining a constant current in an arc circuit is shown diagramatically in Fig. 61. The current leaving the positive brush of the dynamo (D) divides at the junction of the field magnet coils (F M) and the shunt (S) part, passing through the former, and part through the latter. Included in the shunt circuit (S) is a variable resistance (C) composed of a pile of carbon slabs or blocks, arranged one upon another in a press in such a manner that the current passing in the shunt must pass from one block to another. These slabs, when pressed together, conduct well; but

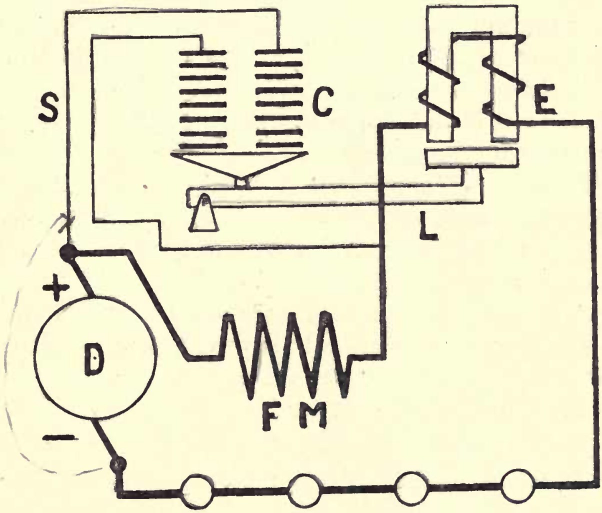

FIG. 61.

when the pressure is diminished, their imperfect contact greatly increases the resistance of the shunt. Hence, when the lever and armature (L) is raised or lowered by the action of the current flowing in the solonoid or electro-magnet (E), which is included in the main circuit, the pressure on the slabs is increased or diminished, and the resistance of the shunt varied in proportion. If now some of the lamps be cut out of circuit by short-circuiting them, the resistance of the circuit will be diminished, and there will be a tendency for the current to increase above its normal value. This increase of current will cause the solonoid (S) to attract the lever (L) with greater force, resulting in an increase of pressure on the carbon slabs, and a diminution of the resistance of the shunt. As a consequence, a larger proportion of the total current flowing will be shunted across the field coils, and the magnetic field being thus weakened, the E. M. F. of the machine will be correspondingly reduced, and the current thus maintained at its normal value.

Regulation by Variation of Speed of Armature.—The voltage and output of series dynamos can be governed to some extent by varying the speed of the armature, by opening or closing the stop-valve of the steam engine, or other motor driving the dynamo. This method of regulation is, however, only applicable in cases where the fluctuations of the load are small, since it involves constant attendance on the engine.

Electric Governor.—To obviate this constant attention to the engine when this system of regulation is adopted, an electric governor is frequently employed. One of the best known types of electric governor is that of Richardson, manufactured by Messrs Robey & Co., Lincoln. This governor may be used for maintaining either a constant pressure, or a constant current in a circuit, and is shown fitted to a steam engine in Fig. 62. The governor consists of a solonoid (E), the cores of which are attached to the end of a lever (L), the short end of which presses through the medium of a plunger (P), direct upon the

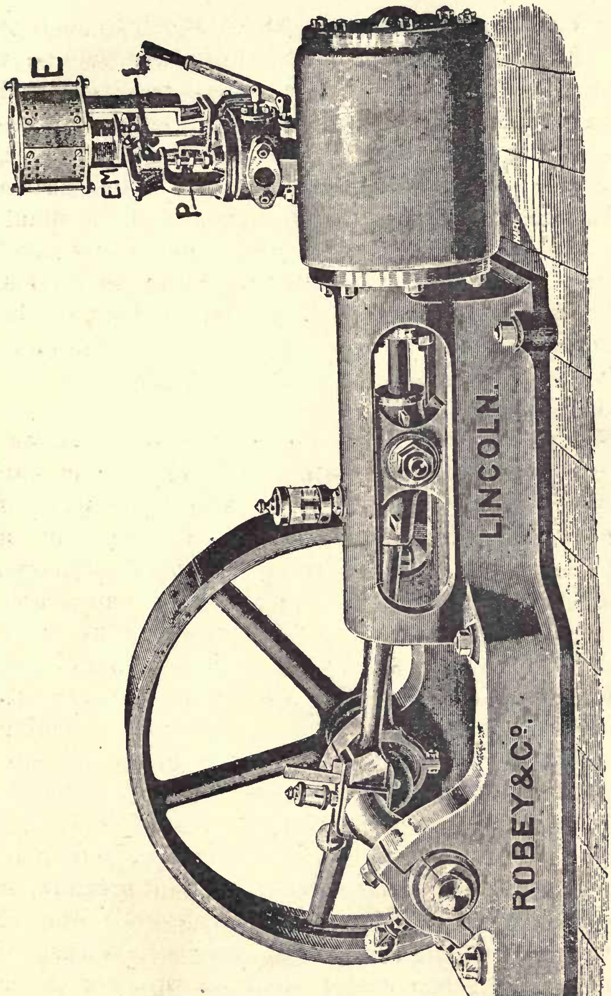

FIG. 62.

stalk of a double-beat cornish valve. The valve fits freely into its seat, and works almost without friction. It is, however, so arranged that the steam gives it a constant pressure upwards. This is balanced at the other end by a spring, and as the leverage is six to one, the spring only needs to exert a sixth of the pressure. There are therefore two forces acting in contrary directions, and nearly balancing each other, and when an electric current is sent through the coils of the solonoid (E), which, when intended for maintaining a constant current, are included in the main circuit, the cores are drawn further in, and the valves partially closed. The parts are so balanced and adjusted that the slightest change in the strength of the current is at once felt and responded to by the engine, and the speed of the armature adjusted to suit the work being done. As an additional precaution, a separate small electro-magnet (E M) is included in the circuit of the solonoid, which, when the current is flowing therein, holds up the iron block (B). If from any cause the circuit is broken, the block (B) falls, and instantly cuts off the steam, thus stopping the engine.

Regulation by Variation of Position of Brushes on Commutator.—In both ring and drum armatures, when rotating in a bi-polar field, there are two points situated at opposite extremities of a diameter of the commutator, at one of which the potential is a maximum, and at the other a minimum, and it is at these points that the brushes must be placed, in order to obtain the greatest difference of pressure. From the point of maximum potential to the point of minimum potential either way round the commutator, the pressure gradually decreases in value. Hence, if the brushes make contact at points on the commutator other than the neutral points or points of highest and lowest potential, the pressure between the brushes will vary in proportion to their distance from the neutral points, increasing as they approach the neutral points, and decreasing as they recede from them, until when making contact at points situated at about 90° from the neutral points, they will be at nearly the same potential. From this it follows that by merely rocking the brushes round the commutator, the pressure at the terminals of the machine may be varied and regulated as required. Such a method of regulation cannot, however, be used with advantage in ordinary dynamos, owing to the very destructive sparking which takes place at the brushes when they are moved any considerable distance from the neutral points. Special dynamos have been designed, notably by Statter, to meet the special requirements of this method of regulation, and in which the sparking at the brushes is obviated at all loads within the range of the machine, but as these have not come into general use they need not be further considered here.

Regulation of Shunt Dynamos.—In parallel incandescent lighting, it is absolutely necessary to maintain the pressure at the lamps at a constant value. When the lamps are situated at a considerable distance from the machine, as in town lighting, this necessitates a constantly varying pressure at the machine in order to make up for the fall of pressure in the mains connecting the machine to the lamps, which fall is dependent on the amount of current flowing in the mains. The ease with which this variation of pressure can be effected in the shunt dynamo causes this class of machine to be ordinarily used in central stations for incandescent lighting, the regulation being effected by either of the following methods, or by both in conjunction. (1) *Variation of strength of magnetising current.* (2) *Variation of speed of armature.*

(1.) **Regulation by Variation of Strength of Magnetising Current.**—This is the only thoroughly efficient method of regulation for a shunt dynamo.

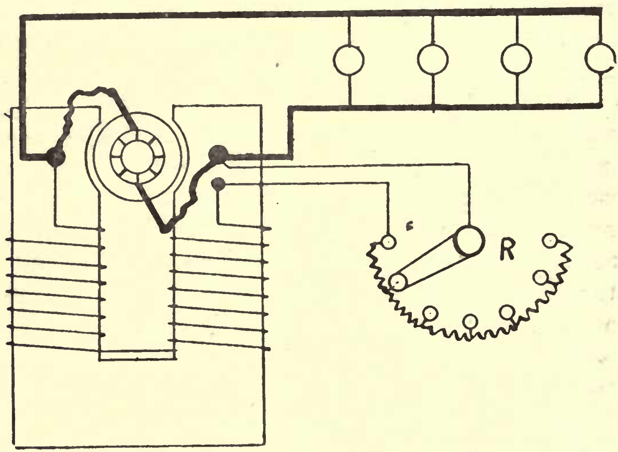

FIG. 63.

The variation in the strength of the magnetising current is effected by means of a hand regulator or rheostat, similar to that represented in Fig. 60, which is inserted in the shunt circuit of the machine, as shown diagramatically in Fig. 63. In this system of regulation, the resistances of the field magnet shunt windings and of the regulator coils are so proportioned, that, when no load is on the dynamo, and all the coils of the regulator are in circuit with the shunt, the machine generates the normal pressure required at the lamps. As more and more lamps are switched on, the voltage at the lamps has a tendency to decrease, and therefore the pressure at the machine must be raised in proportion. This is effected by moving the lever of the regulator (R), so that fewer resistance coils are included in the shunt circuit; the resistance of the latter being thus decreased, the exciting current and voltage of the machine is increased correspondingly. This method of regulation is common with all in which resistances are included in the circuit, wastes energy to a certain extent, but the quantity so wasted is so small in proportion to the whole that it may be considered as of little moment, especially when the advantages of the system are taken into account. It is possible, of course, to use this method in conjunction with regulation by means of the engine stop-valve (the stop-valve being used for large variations of pressure, and the hand regulator for small variations), but the advantages of the system are so few that in the generality of cases the hand regulator is solely relied on to cope with any variations in the load. The engines are then so arranged that they can be run entirely upon their governors, these being so adjusted as to merely prevent the engine racing in case of the load being suddenly taken off the machine, through a short circuit, or other breakdown, the stop-valves being fully opened as soon as the machines have taken the load.

Regulation by Variation of Speed of Armature.—A much less satisfactory method of regulation for shunt dynamos is that of varying the speed of the armature. For small variations of pressure, the alteration of speed can be readily effected by means of an adjustable governor, the speed of the armature being varied by increasing or diminishing the tension of the governor spring, according to the pressure required at the terminals of the machine. For larger variations, however, the only effective method of regulation is by means of the stop-valve, that is to say, the main stop-valves of the engines are opened or closed in proportion to the pressure required. When a number of dynamos are running in parallel, the disadvantages of this system, as compared with the method of varying the strength of the magnetic field, become especially prominent, since, in place of a number of easily adjusted hand regulators, fixed in some central position, and operated by a single attendant, this method involves the regulation being effected by probably as many men as there are engines, each regulating the stop-valve of a particular engine. Furthermore, the regulation is not nearly so effective, owing to the difficulty of expeditiously adjusting the valves to give the pressure required. In connection with this particular system of regulation, a special type of voltmeter is generally employed, this being of extraordinary large dimensions, with the index or pointer about 18 inches in length, so that its indications may be seen all over the engine-room.

Regulating Compound Dynamos.—A carefully compounded dynamo will, when run at the speed for which it was designed, regulate itself perfectly, and maintain a constant difference of potential at its terminals under any variation of load within its range. In practice, however, it is not always possible to work a dynamo under these exact conditions, and, moreover, in the case of large machines, the effect of temperature upon the resistance of the machine has an appreciable effect upon the voltage. Means for regulating the latter are therefore desirable. The voltage may be varied to a certain extent by suitably adjusting the governor of the driving engine, increasing or decreasing the speed; but in many cases this is not very desirable or possible, and a much better method of obtaining the desired variation of voltage is to insert a variable resistance or hand regulator in the shunt circuit of the machine, the resistance of the shunt being suitably proportioned to give the requisite margin for regulation.

Regulating Over-Compounded Dynamos.—It is sometimes desirable, as in central light and power stations, to have a dynamo which will maintain a constant pressure at a point some distance from the machine. In this case the dynamo is over-compounded, or the series coils are wound with a greater number of turns, in order to raise the pressure at the terminals of the machine as the load increases, and thus compensate for the fall of pressure in the mains. As it is frequently necessary to vary the degree of over-compounding, the series coils of such dynamos are usually so proportioned as to give from 10 per cent. to 20 per cent. of over-compounding, and a strip or ribbon of German silver or copper is arranged as a shunt to the series coils. By suitably including a greater or lesser length of ribbon in the circuit, the resistance of the variable shunt and the amount of current flowing in the series coils can be varied, and the percentage of over-compounding adjusted accordingly.

CHAPTER IX.

COUPLING DYNAMOS.

WHEN it is needful to generate a large and variable amount of electrical energy, as is the case in large installations and central generating stations, apart from the question of liability to breakdown, it is neither economical nor desirable that the whole of the energy should be furnished from a single dynamo. Since the efficiency of a dynamo is dependent upon its output at any moment, or the load at which it is worked, the efficiency varying from 95 per cent. at full load to 80 per cent. at half load, it is obviously advisable in order to secure the greatest economy in working to operate any dynamo as far as possible at full load. Under the above circumstances, when the whole of the output is generated by a single dynamo this can evidently not be effected, for the load will naturally fluctuate up and down during the working hours, as the lamps, motors, &c., are switched into and out of circuit; and hence, although the dynamo may be working at full load during a certain portion of the day, at other times it may probably be working below half load, and therefore the efficiency and economy in working in such an arrangement is very low. In order to secure a maximum efficiency, it is usual in such cases to divide up the generating plant into a number of units, varying in size, so that as the load fluctuates it can either be shifted from one dynamo to another as the exigencies of the case requires; or when the load exceeds the capacity of the largest dynamo in the plant, the output of one can be added to that of another, and thus the dynamos actually at work at any moment can be operated as nearly as possible at full load. As it is necessary to take certain precautions in connecting one dynamo to another, in order that the other dynamos may not be effected by the change, and that they may work satisfactorily together, it is well to consider these in connection with the different types of machines.

Series and Parallel Connections.—Since the output of a dynamo is made up of two factors, viz., the pressure and the current respectively, it follows that the output of a machine may be increased by increasing either the one or the other, or both at the same time. As however the systems of distribution in use at the present time involve the maintenance of either *a constant current* or a *constant pressure* in a circuit, the methods of coupling dynamos together resolve themselves into two kinds, corresponding to the systems of distribution, viz., *parallel* and *series* connections. In coupling two or more machines in parallel, the pressures of all the machines are kept at a constant value, while the output of the plant is increased in proportion to the current capacities of the machines in circuit. In the series coupling, the current capacity of the plant is kept at a constant value, while the output is increased in proportion to the pressures of the machines in circuit.

Shunt Dynamos in Series.—The simplest opera-

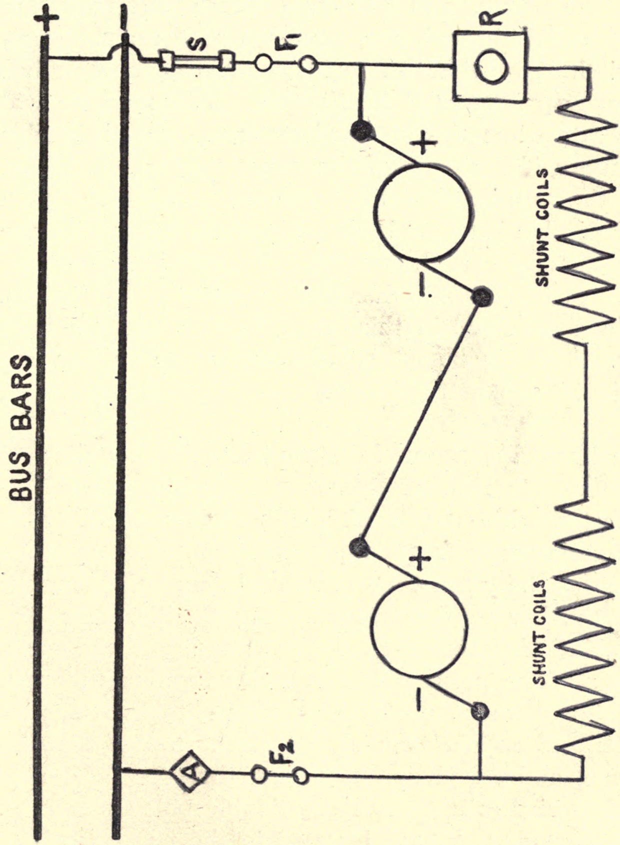

FIG. 64.

tion in connection with the coupling of dynamos, and the one used probably more frequently in practice than any other, is the coupling of two or more shunt dynamos to run either in series or in parallel. When connected in series, the positive terminal of one machine is joined to the negative of the other, and the two outer terminals are connected through the ammeter A, fuses F_1 F_2, and switch S, to the two main conductors or omnibus bars as represented in Fig. 64. The machine will operate when the connections are arranged in this manner, if the ends of the shunt coils are connected to the terminals of the respective machines; but a better plan is to put both the coils in series with one another, so that they form one long shunt between the two main conductors, as shown in Fig. 64. When arranged in this way, the regulation of both machines may be effected simultaneously by inserting a hand regulator (R) in series with the shunt circuit, as represented.

Shunt Dynamos in Parallel.—The coupling of two or more shunt dynamos to run in parallel is effected without any difficulty, and is probably an operation more frequently performed than any other, it being daily practised in central generating stations on the low tension system. Fig. 65 illustrates diagramatically the method of arranging the connections. The positive and negative terminals of each machine are connected respectively to two massive insulated copper bars, shown at the top of the diagram, and called omnibus bars, through the double pole switches S_1 S_2, and the double pole fuses F_1 F_2. Ammeters, A_1 A_2, are inserted in the main circuit of each machine, and serve to indicate the amount of current generated by each. An automatic switch or cutout, AC_1 AC_2, is also shown as being included in the main circuit of each of the machines, although this appliance is sometimes dispensed with. The pressure of each of the machines is regulated independently by means of the hand regulators R_1 R_2,

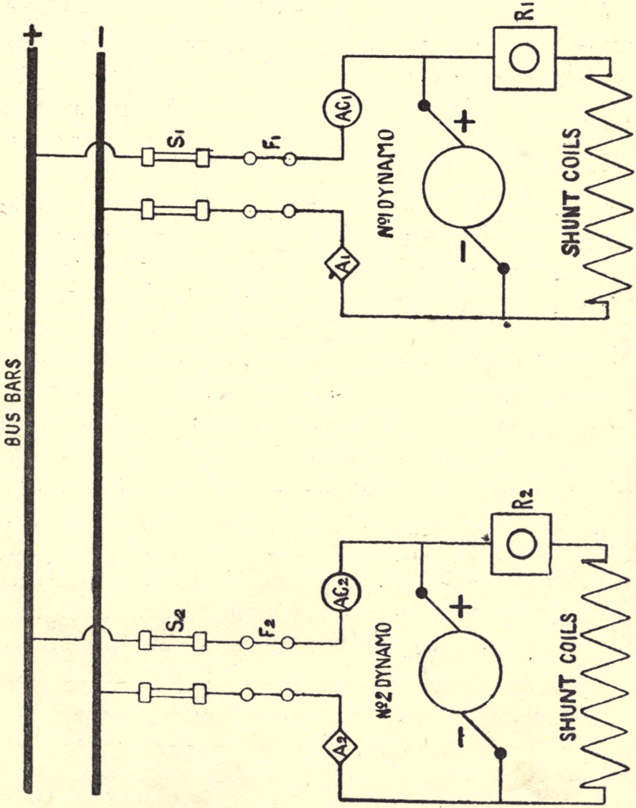

FIG. 65.

inserted in series with the shunt circuit. The shunt circuits are represented as being connected to the positive and negative terminals of the respective machines, but in many cases, where the load is subjected to sudden variations, and when a large number of machines are connected to the bus bars, the shunt coils are frequently connected direct to these; and in such circumstances this method is preferable, as by means of it the fields of the idle dynamos can be excited almost at once direct from the bus bars by the current from the working dynamos, and hence if a heavy load should come on suddenly, no time need be lost in building up a new machine previous to switching it into parallel. The pressure of the lamp circuit is given by a voltmeter, whose terminals are placed across the omnibus bars; and the pressure at the terminals of each of the machines is indicated by separate voltmeters or pilot lamps, the terminals of which are connected to those of the respective machines.

Switching Dynamo into and out of Parallel.— In order to put an additional dynamo into parallel with those already working, it is necessary to run the new dynamo up to full speed, and, where it excites, regulate the pressure by means of a hand regulator until the voltmeter connected to the terminals of the machines registers one or two volts more than the voltmeter connected to the lamp circuit, and then close the switch. The load upon the machine can then be adjusted to correspond with that upon the other machines by means of the hand regulator. In this class of machine there is little or no danger of overloading an armature when connecting it to the bus bars, and therefore the pressure need not be adjusted with very great accuracy; in fact, it is common practice in central stations to judge of the voltage of the new dynamo merely by the appearance of its pilot lamp. When shutting down a machine, the load or current must first be reduced, by gradually closing the stop-valve of the engine, or inserting resistance into the shunt circuit by means of the hand regulator; then when the ammeter indicates nine or ten amperes, the main switch is opened, and the engine stopped. By following this plan, the heavy sparking at the switch contacts is avoided, and the tendency for the engine to race reduced. Great care, however, has to be taken that the current is not reduced too far, or otherwise there is a risk of the machine being stopped, receiving a back current from the other dynamos, resulting in heavy sparking at the commutator, and in the machine being driven as a motor. To obviate this danger, and to render these precautions needless, shunt dynamos when running in parallel are frequently provided with automatic cutouts, set so as to automatically switch out the machine when the current falls below a certain minimum value.

Dividing Load.—If a plant composed of shunt dynamos running in parallel be subjected to variations of load, gradual or instantaneous, the dynamos will, if they all have similar characteristics, each take up an equal share of the load; if, however, as is sometimes the case, the characteristics of the dynamos are dissimilar, the load will not be shared equally; the dynamos with the most drooping characteristics taking less than their share with an increase of load, and more than their share with a decrease of load. If the difference is slight, it may readily be compensated by means of the hand regulator increasing or decreasing the pressures of the machines, as the load varies or fluctuates. If, however, the difference is considerable, and the fluctuations of load very rapid, it becomes practically impossible to evenly divide the load by this means so that each dynamo takes up its proper share of the work. Under such circumstances, the pressure at the bus bars is liable to great variations, and there is also great liability for the fuses of the overloaded dynamos to be blown, thus precipitating a general breakdown. To cause an equal division of the load amongst all the dynamos, under such circumstances, it is needful to insert a small resistance in the armature circuits of such dynamos as possess the straightest characteristics, or of such dynamos as take more than their share of an increase of load. By suitably adjusting or proportioning the resistances, the pressures at the terminals of all the machines may be made to vary equally under all variations of load, and each of the machines will then take up its proper share of the load.

Automatic Cutouts.—Shunt and other dynamos are always liable when working to have the pressure at their terminals reduced, either through a fault in the armature or field circuits, or through a hot bearing or other cause. When a number of shunt dynamos are running in parallel, and the pressure of one falls below that of the others, the load is transferred from the machine having the lower pressure to the machine with the higher pressure, until when the pressure falls below a certain minimum value a reverse current is sent through the armature of the machine whose pressure has been reduced by the machines having the higher pressure. This results in the machine being driven as a motor, and in great sparking at the commutators of all the dynamos, and also in an overload of the driving dynamos, and probably in the blowing out of all the fuses. In order to prevent this occurring, shunt dynamos when running in parallel are each as a rule provided with an automatic switch, placed between one or both of the machine terminals and the omnibus bars, whose duty it is to switch off automatically the machine in the event of a reduction of its voltage from any of the above-mentioned causes. The principle and action of this instrument will be understood by reference to Fig. 66, which represents the form manufactured and used for this purpose by Messrs Crompton & Co. Briefly described, the instrument consists of an electro-magnet, fixed upon a slate base, and shown in the upper portion of the figure; and an iron armature fixed to the ends of the pivoted levers of the switch, shown in the lower portion of the figure. The electro-magnet is included in series with the

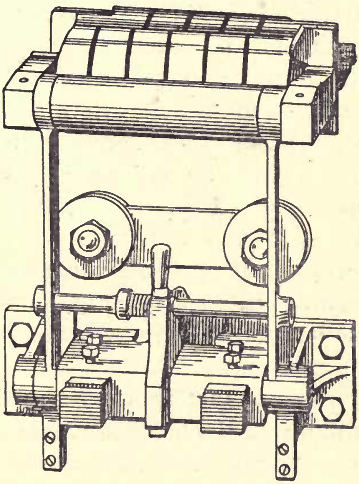

FIG. 66.

switch and armature circuit, and while the pressure of the machine to which the instrument is connected remains at its normal value, the current flowing in its coils is sufficiently strong to enable it to hold up the iron armature against its pole pieces. If from any cause the voltage of the machine is reduced, the current flowing in its armature is decreased also, until when it falls below a certain minimum value at which the automatic switch is arranged to act, the strength of the electro-magnet has been so far diminished that it can no longer hold up the armature against the weight of the levers, and these latter therefore drop and switch the machine out of circuit. A fusible cutout is shown in the centre of the figure, which, when the current exceeds the safe capacity of the machine, melts, and cuts out the armature, thus saving it from destruction.

Coupling Series Dynamos in Series.—Series wound dynamos will run satisfactorily together without special precautions when coupled in series, if the connections are arranged as in Fig. 67. The positive terminal of one dynamo is connected to the negative terminal of the other, and the two outer terminals are connected directly to the two main conductors or bus bars through the ammeter A, fuse F, and switch S. If it be desired to regulate the pressure and output of the machines, variable resistances, or hand regulators R_1 R_2, may be arranged as shunts to the series coils, as represented, so as to divert a portion or the whole of the current therefrom.

Series Dynamos in Parallel.—Simple series wound dynamos not being well adapted for the purpose of maintaining a constant pressure, are seldom in practice coupled in parallel; the conditions of working, however, derive importance from the fact that compound dynamos, being provided with series coils,

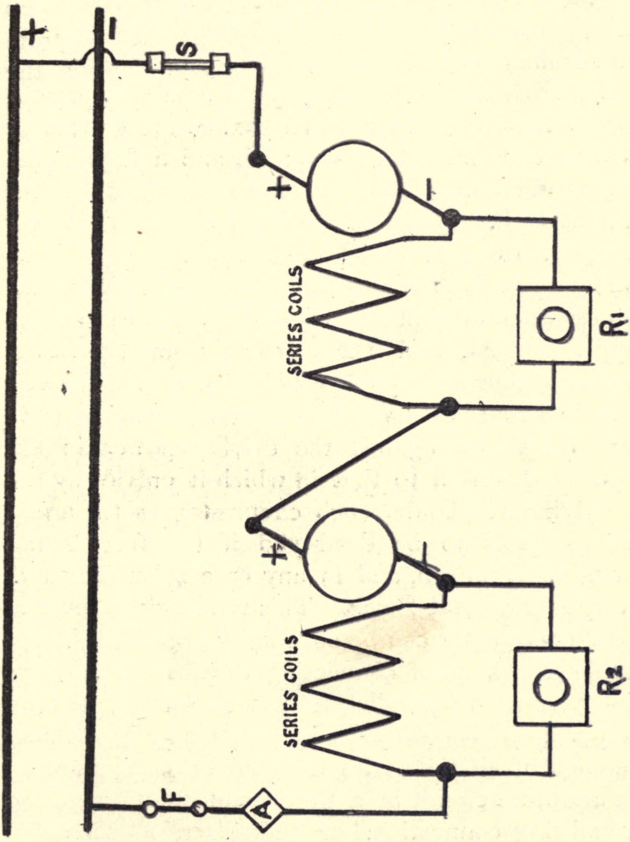

Fig. 67.

are subject to similar conditions when working in parallel, which is frequently the case. In coupling two or more plain series dynamos in parallel, the same procedure cannot be followed as in the case of plain shunt dynamos, for the reason that if the voltage of the new dynamo is exactly equal to that of the bus bars when connected in parallel, the combination will be unstable. If from any cause the pressure at the terminals of one of the dynamos falls below that of the others, it immediately takes a smaller proportion of the load; as a consequence, the current in its field coils is at once reduced, and a further fall of pressure immediately takes place owing to this circumstance. This increased fall of pressure again causes the dynamo to relinquish a portion of its load, and again occurs a further fall of pressure. Thus the process goes on, until finally the dynamo ceases to supply current, and the current from the other dynamos flowing in its field coils in the reverse direction reverses its magnetism, and causes it to run as a motor against the driving power in the opposite direction to that in which it previously ran as a dynamo. Under such circumstances the armature is liable to be destroyed if the fuse is not immediately blown, and in any case is subjected to a very detrimental shock. This tendency to reversal in series dynamos can be effectually prevented by the simple expedient of connecting the field coils of all the dynamos in parallel, as was first suggested by Gramme. This is effected in practice by connecting the ends of all the series coils where they join on to the armature circuit by a third connection, called the "equalising connection," or "equaliser," as shown in Fig. 68. The immediate effect of this equalising connection is to cause the whole of the current generated by the plant to be divided among the series

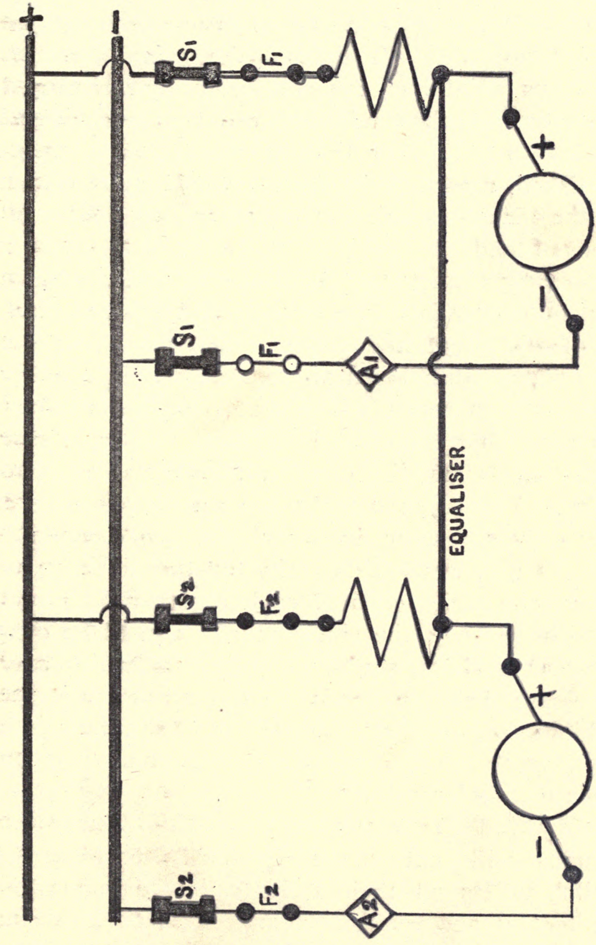

Fig. 68.

coils of the several dynamos in the inverse ratio of their resistance, without any regard as to whether this current comes from one armature, or is divided among the whole. The fields of the several dynamos being thus maintained constant, or at any rate caused to vary equally, the tendency for the pressure of one dynamo to fall below that of the others is much diminished, reversal of polarity is entirely obviated, and the machines will run together under all conditions of load.

Coupling Compound Dynamos in Series.—Since compound dynamos may be regarded as a combination of the shunt and series wound machines, and as no special difficulties are experienced in running these latter in series, analogy at once leads to the conclusion that compound dynamos under similar circumstances may be coupled together with equal facility. This is found to be the case in practice, it being only necessary, in order that two compound dynamos may run satisfactorily together in series, to connect the series coils of each together, as represented in Fig. 67; the shunt windings must be connected as a single shunt, as in Fig. 64, which may either extend simply across the outer brushes of the machines, so as to form a double short shunt, or may be a shunt to the bus bars or external circuit, so as to form a double long shunt.

Compound Dynamos in Parallel. — Compound dynamos will not run satisfactorily together in parallel, unless all their series coils are connected together by an equalising connection, as in series dynamos. Two methods of arranging the connections are adopted in practice, these being illustrated in Figs. 69 and 70. Either of these methods is satisfactory, but that shown in Fig. 70 is preferable, as by means of it the idle machines are completely disconnected from those at work. The same reference letters are common in both diagrams—S_1 S_2

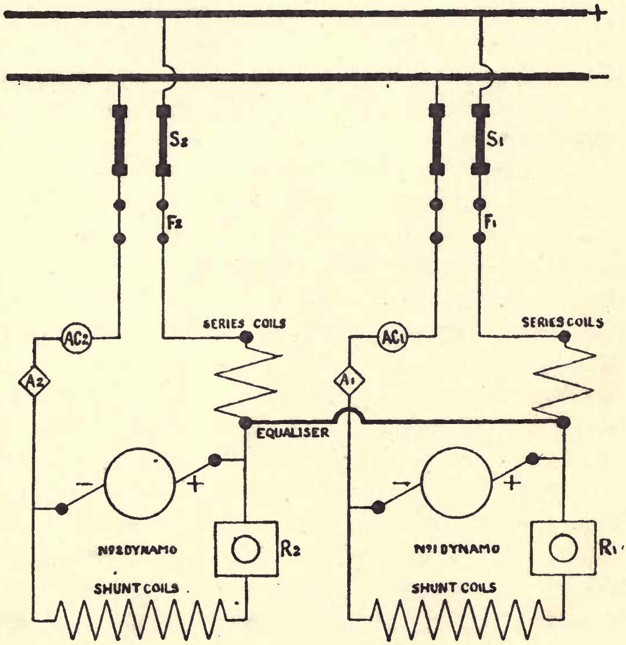

FIG. 69.

are switches; F_1 F_2 fuses; A_1 A_2 are ammeters, which indicate the total amount of current generated by each of the machines; AC_1 AC_2 are automatic switches, arranged for automatically switching out a machine in the event of the pressure at its terminals being reduced through any cause; R_1 R_2

are hand regulators, inserted in the shunt circuits of each of the machines, by means of which the pressures of the individual machines may be varied and the load upon each adjusted. The pressure at the bus bars is given by the voltmeter V, one

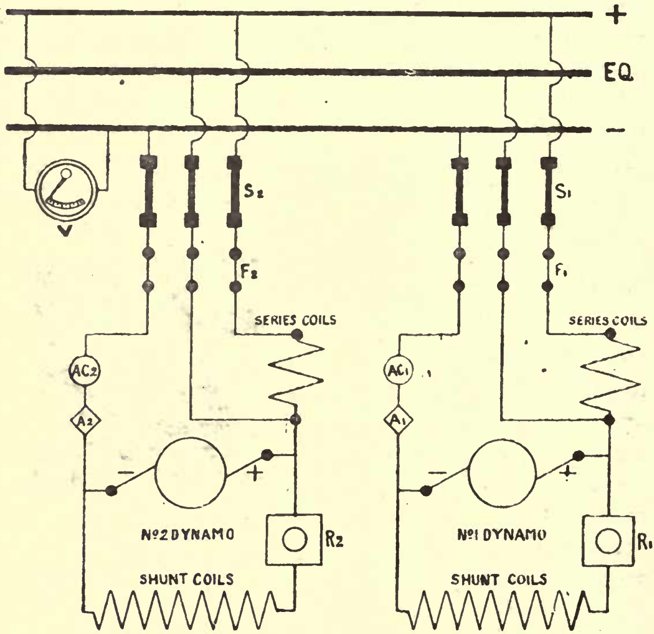

FIG. 70.

terminal of which is connected to each of the bars; a second voltmeter may be used, to give the pressure of any individual machine, by connecting "voltmeter keys" to the terminals of each of the machines, or a separate voltmeter may be used for each individual machine. The only essential difference between the two diagrams is, that in Fig. 69 the equaliser is connected direct to the positive brushes of all the dynamos, whilst in Fig. 70 the equaliser is brought up to the switchboard and arranged between the two bus bars, a switch being fitted for disconnecting it from the circuit when the machine to which it is connected is not working. In connection with this latter arrangement the form of switch shown in Fig. 71 is generally used. This consists of three contacts, insulated from each other, and fixed upon a slate base; the two contacts at the sides are respectively connected to the positive and negative conductors, while the central contact is connected to the equaliser. The circuits are opened or closed simultaneously by means of three levers, which are forced between the contacts by the handle. These levers are each provided with removable knife contacts for taking the spark at breaking contact, and are insulated from each other, and rigidly fixed upon a spindle which is capable of a small angular movement in the bearings, shown in the lower part of the figure.

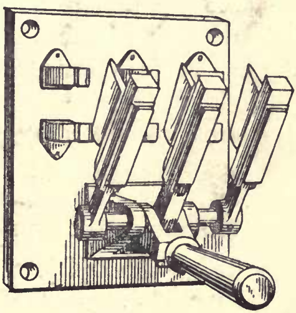

FIG. 71.

Switching Dynamo into and out of Parallel.—If the characteristics of all the dynamos are similar, and the connections are arranged as in either Figs. 69 or 70, the only precaution to be observed in switching a new machine into parallel is to have its voltage equal, or nearly equal, to that of the bus bars previous to closing the switch. If this is the case, the new machine will instantly take up its due share of the load without disturbance or shock of any kind. If a dynamo is to be cut out of circuit, it will first be necessary to reduce the load to a few amperes, as in the case of shunt dynamos, either by easing down the engine, or by cutting resistance into the shunt circuit by means of the hand regulator, and then open the switch. Previous to this, however, it is advisable to increase the voltage at the bus bars to a slight extent, as while slowing down the engine the load upon the outgoing dynamo is transferred to the other dynamo armatures, and the current in their series coils not being increased in proportion the voltage at the bus bars is consequently reduced somewhat.

Dividing Load.—When a number of compound dynamos of different outputs, size, or make are running together in parallel, it frequently happens that all their characteristics are not exactly similar, and therefore the load is unequally distributed amongst them, some being overloaded, whilst others do not take up their proper share of the work. If the difference is small, it may be compensated by means of the hand regulator; if large, however, other means must be taken to cause the machines to take up their due proportion of the load. If the series coils of the several dynamos are provided with small adjustable resistances, in the form of german silver or copper ribbon inserted in series with the coils, the distribution of the current in the latter may be altered by varying the resistance attached to the individual coils, and thus the effect of the series coils upon the individual armatures in raising the pressure may be adjusted, and the load thus evenly divided among the machines.

CHAPTER X.

RUNNING DYNAMOS.

Dynamo Foundations.—The first essential for success in dynamo running is to have the machine firmly and securely fixed upon a good and sound foundation; for no dynamo, however well constructed and managed, will run well unless this is the case, the vibration engendered by a bad foundation resulting in sparking at the brushes, and in other evils which greatly tend to reduce the life of the commutator and other parts of the machine. It is also advisable, if the machine is belt or rope driven, to mount it upon a sliding bedplate provided with brackets and tightening screws for aligning and adjusting the tension of the belt while the machine is running. The foundation may be of wood, stone, brick, or concrete. Wood, as a rule, is only used in making foundations of a temporary character, the other materials being used for more permanent foundations.

Brick or Stone Foundations.—In making either brick, stone, or concrete foundations, the excavation should be carried far enough down to secure a good bottom. The foundation, if of brick or stone, should be built up in cement to a suitable height, and a large flat stone cemented on the top. In the case of small dynamos, it will only be necessary to carry the holes for the holding-down bolts from 6 to 8 inches into the foundation. With large dynamos, however, the holes should be carried as far down as possible, and the holding-down plates, of wrought or cast iron, built in. Underneath each of the plates hand holes should be made, so that the cotters may be inserted into the bolts when these latter are being fixed in position.

Concrete Foundations.—In making concrete foundations, the simplest plan, for small dynamos, is to make a few taper wooden boxes, a few inches square and of suitable length, and nail them on to a template of the base of the machine where the holding-down bolts will come. Having firmly fixed the template, with the boxes in position, the concrete may be run in. When hard, the boxes and template may be removed, leaving holes in the concrete for the holding-down bolts. In the case of large dynamos, the holding-down bolts should be built in at the time the foundation is made. In this case, the bolts, provided with holding-down plates and narrow taper boxes, or metal tubes of suitable length, are slung in the holes in the template, and the concrete is run in. The bolts being loose in the boxes, are thus capable of a little lateral play while firmly fixed longitudinally.

Height of Foundations.—It is advisable, in all cases, to carry the top of the foundations of both large and small dynamos to a few inches above the surface of the surrounding ground or floor. The dynamo is thus kept clear of any water which may accumulate. In the case of small dynamos, it will generally be found necessary, in order to keep the belt from coming into contact with the ground, and to enable the brushes to be more conveniently adjusted, to carry the top of the foundation up to from 12 to 24 inches above the surface of the ground.

Fixing Dynamos.—In fixing either direct or belt-driven dynamos, it will first be necessary to ascertain, with a spirit-level and long straight-edge, whether the top of the foundation is level and true. If this is found to be the case, the holding-down bolts should be dropped into the holes in the foundation, if they are not already built in, and the dynamos carefully placed thereon, the ends of the bolts being passed through the holes in the bedplate and secured by a few turns of the nuts. The dynamo should then, if belt driven, be carefully aligned with the driving pulley or fly-wheel. In order that the belt may run true on the pulleys, it is needful that a straight line joining the two pulleys should pass through the centre of the face of the driving pulley and the centre of the face of the dynamo pulley. To effect this, when both pulleys are equal in width across the face, a fine cord is stretched perfectly straight from one pulley to the other across the edges lying in one plane; then, by adjusting the position of the dynamo, the cord can be made to touch the two edges of one side of the driving pulley and the two edges of one side of the dynamo pulley, when the pulleys will be truly aligned, and the machine set square with the driving shaft. If one of the pulleys is wider across the face than the other, the difference should be carefully noted, and allowance made when lining off. Too much attention cannot be paid to getting the pulleys truly aligned, as the belt is liable to drop off when the machine is started if this is not the case. The dynamo bedplate, and also, if possible, the armature shaft, should next be carefully and finally tested with a spirit-level, and if not found truly level, the machine should be packed up until perfectly level either way. Having carefully aligned the pulleys and levelled the machine, it should next be grouted with thin cement. This is effected by arranging a wall of bricks or a few wooden battens around the bedplate of the machine, leaving a few inches clear all round, and stopping up all holes with clay or stiff cement. Thin cement is then run in until the holding-down bolt-holes are full, and the cement has risen to the level of the underside of the bedplate. When the cement is set hard, the bricks or wooden battens may be removed, and the edges of the foundation trimmed off, and the nuts of the holding-down bolts screwed up tight and the machine securely fixed.

Preliminary Examination of Machine.—When the machine has been securely fixed, and previous to the first starting, the whole of the machine should be carefully examined to see that all parts are in good order, and have not been damaged. The field magnet circuit should first be inspected to see that none of the wires or connections have been broken or are loose, and that the coils are correctly coupled up. The caps of the bearings should next be taken off, and these and the journals carefully cleaned from all grit and dirt. They should then be oiled, and the caps replaced and screwed up with the hand only. The gaps between the outer surface of the armature and the polar faces should be examined in order to ascertain whether any foreign body, such as a small screw or nail, has lodged therein. If such is the case, it should be carefully removed with a bit of wire. The guard plates protecting the armature windings should also be removed, and the windings carefully inspected by slowly rotating the armature, to see that they are not damaged, and that the insulation is perfect. The armature should then be finally rotated by hand to see that it revolves freely, and that the bearings are securely fixed. The commutator and brushes should next receive attention,—the commutator, to see that it is not damaged in any way through one or more of the segments being knocked in, or the lugs being forced into contact with one another; and the brush-holders and brushes, to see that the latter are clean and make good contact with the brush-holders or flexible leads, and the former to see that they work freely on the spindle, and that the hold-off catches work properly. In the subsequent working of the dynamo it will of course not be necessary to follow the whole of these proceedings every time the machine is started, as it is extremely unlikely that the machine will be damaged from external causes whilst working without the attendant being aware of the fact. Having ascertained that the machine is not injured in any way, and that the armature revolves freely, the adjustment of the brushes should next be proceeded with.

Adjustment of Brushes.—The adjustment of the brushes upon the commutator requires careful attention if sparking is to be avoided. The points upon the commutator at which the tips of the brushes, carried by opposite arms of the rocker, bear upon the commutator, should be, in bi-polar dynamos, at opposite extremities of a diameter. In multipolar dynamos the positions vary with the number of poles and the nature of the armature winding. In order to facilitate the correct setting of the brushes upon the commutator, *setting* marks are usually cut in the collar of the commutator next to the bearing. In bi-polar dynamos, these setting marks divide the circumference of the commutator into equal parts. In adjusting the brushes, the tips of all the brushes carried by one arm of the rocker are set in correct line with the commutator segment marked out by one setting mark, and the tips of the brushes carried by the other arm or arms are set in correct line with the segments marked out by the other mark or marks. If one or more brushes in a set are out of line with their setting mark, it will be necessary to adjust the brushes up to this mark by pushing them out or drawing them back, as may be required, afterwards clamping them in position. When adjusting the brushes the armature should always be rotated, so that the setting marks are horizontal. The rocker can then be rotated into position, and the tips of both sets of brushes conveniently adjusted to their marks. In those brush-holders provided with an index or pointer for adjusting the brushes the setting marks upon the commutator are absent, the length of the pointer being so proportioned that when the tips of the brushes are in line with the extreme tips of the pointers, the brushes bear upon the correct positions on the commutator.

Bedding Brushes.—Having adjusted the brushes to their correct positions upon the commutator, their tips or rubbing ends should next be examined, whilst in position, to see that they bed accurately on the surface of the commutator. In many instances it will be found that this is not the case, the brushes sometimes bearing upon the point or toe, and sometimes upon the heel, so that they do not make contact with the commutator throughout their entire thickness and width. The angle of the rubbing ends will therefore need to be altered by filing to make them lie flat.

Filing Brushes.—When the brushes do not bed properly upon the commutator, and filing has to be resorted to in order to alter the angle of the brush tips or ends, it will be found necessary to fix the brush in a holder or filing clamp, in order that the correct angle may be conveniently obtained. This, as a rule, is supplied with the machine, and consists of two pieces of metal, both shaped at one end to the correct angle (usually 45°), to which the brushes must be filed. One of the pieces of metal (the back part) has a groove sufficiently large to accommodate the brush, which is clamped in position by the other piece of metal and a pinching screw. If the clamp is not supplied, a convenient substitute can be made out of two pieces of wood about the same width as the brush. One end of each piece of wood is sawn to the correct angle, and the brush is placed between the two. In filing, the brush is fixed in the clamp, with the toe or tip projecting slightly over the edge of the clamp, and the latter being fixed in a vice, the brush is filed by single strokes of a smooth file made outwards, the file being raised from contact with the brush when making the back stroke.

Pressure of Brushes upon Commutator.—Having ascertained that the brushes are correctly placed and bedded upon the commutator, it remains to adjust their pressure upon the latter. This is effected by regulating the tension of the springs provided for the purpose upon the brush-holders. The tension of the springs should be just sufficient to cause the brushes to make a light yet reliable contact with the commutator. The contact must not be too light, otherwise the brushes will vibrate, and thus cause sparking; nor must it be too heavy, or they will press too hard upon the commutator, grinding and scoring and wearing away the latter and themselves to an undesirable extent, and, moreover, giving rise to great heating and sparking. The correct pressure is attained when the brushes collect the full strength of current without sparking, while their pressure upon the commutator is just sufficient to overcome any ordinary vibration due to the rotation of the commutator.

Adjusting Lubricators.—As a rule, sight feed lubricators are used in all but the smallest machines. Previous to starting, these should be examined to see that they feed the lubricant properly, and that the oil passages are not clogged. They should then be adjusted to feed an ample supply of oil on to the armature spindle. The amount required will of course depend upon the load and the nature of the oil used, but from 3 to 12 drops per minute of any ordinary heavy hydro-carbon oil is generally sufficient for a load varying from 6 to 30 horse-power.

Starting Dynamos.—Having attended to the above preliminaries, and having cleared all keys, spanners, bolts, &c., out of the immediate neighbourhood of the machine, and having raised the brushes from contact with the commutator by means of the hold-off catches, the dynamo may be started and allowed to run light. Whilst thus running, the bearings should be tested from time to time to ascertain if they heat unduly, and an opportunity is also afforded, while the dynamo is thus running, for cleaning the commutator, if this is dirty, with finest emery cloth, afterwards wiping clean with a linen rag. The connections of the machine and external circuits should be verified, and all terminals, &c., cleaned and examined. If found correct, the brushes should be let down on to the commutator, and their tips adjusted by rotating the rocker into the neutral points. The tips of the brushes carried by one arm of the rocker will, in bi-polar dynamos with vertical field magnets, bear exactly upon the top or highest point of the commutator, while the tips of those carried by the other arm will bear exactly upon the bottom or lowest point of the commutator. In other types of machines, the positions for the brushes will vary according to the class or form of the field magnet and the system of armature winding. The positions of the brushes in most of the types of dynamos in common use are illustrated in Figs. 21 to 28. If the machine is compound or shunt wound, all switches controlling the external circuits should be opened, as the machine excites best when this is the case; and when the machine is provided with a rhestat or hand regulator and resistance coils, these latter should all be cut out of circuit, or short circuited, until the machine excites, when they can be gradually cut in as the voltage rises. When the machine is giving the correct voltage, as indicated by the voltmeter or pilot lamp, the machine may be switched into connection with the external or working circuits. When the machine is series wound, it is absolutely necessary to have the external circuit closed, otherwise a closed circuit will not be formed through the field magnet windings, and the machine will not excite.

Attention to Dynamo.—When the machine is started and at work, it will need a certain amount of attention to keep it running in a satisfactory and efficient manner. The first point to which attention should be paid is the adjustment of the "lead" of the brushes. If this is neglected, the machine will probably spark badly, and the commutator and brushes will constantly require filing and trimming. The "lead" is the term applied to the slight forward movement which it is found necessary to give to the brushes of most dynamos in order to avoid sparking with an increase of load. This lead in all good dynamos is very small, and varies with the load and class of machine. The best lead to give to the brushes can in all cases be found by rotating the rocker and brushes in either direction to the right or left of the neutral points, until sparking commences increasing with the movement. The position midway between these two points is the correct position for the brushes, for at this position the least sparking occurs, and it is at this position that the brushes should be fixed by clamping the rocker. In series dynamos giving a constant current, such as for arc lamps in series, the brushes require practically no lead. In shunt and compound dynamos the lead varies with the load, and therefore the brushes must be rotated in the direction of rotation of the armature with an increase of load, and in the opposite direction with a decrease of load. In cases where the dynamos are subjected to a rapidly varying or fluctuating load, it is of course not possible to constantly shift the brushes as the load varies, therefore the brushes should be fixed in the positions where the least sparking occurs at the moment of adjustment. If at any time very violent sparking occurs, which cannot be reduced or suppressed by varying the position of the brushes by rotating the rocker, the machine should be shut down at once, otherwise the commutator and brushes are liable to be destroyed, or the armature burnt up. This especially refers to high tension machines. As soon as any abnormal sparking is seen at the commutators of such machines, their speed should be at once reduced, and the commutator cleaned up, and the brushes readjusted. Another very important point to be looked to is the lubrication of the machine. The lubricators should be inspected from time to time, to see that they feed the lubricant properly, and that none of the waste oil passages are clogged. The oil should on no account be allowed to get on to the commutator or brushes, or into the windings of the armature, as it is liable to cause sparking at the brushes, and to destroy the insulation of the armature. In filling the lubricators, oil cans made of some non-magnetic material such as copper, brass, or zinc, should always be used. If iron cans are used, they are liable to be attracted by the field magnets, and thus possibly catch in the armature, and destroy the insulation of the latter. The bearings, and also the field magnet coils, should be tested at intervals, to see that they do not become unduly heated. When testing the temperature of low tension machines, the hand may be used as a guide for judging when the machine is running at a safe temperature. If the heat of any portion can be easily borne by the naked hand, it may be taken that the temperature of the machine is within safe limits. In the case of high tension machines, however, the naked hand cannot be brought with safety into contact with any portion of the machine, and therefore the only way to ascertain if the windings or other electrical parts are at a safe temperature is to apply a thermometer. It may be taken as a safe rule that no part of a working dynamo should have a temperature of more than 80° Fahr. above that of the surrounding air. Hence, if the temperature of the engine-room is noted before applying the thermometer to the machine, it can at once be seen if the latter is working at a safe temperature. In taking the temperature, the bulb of the thermometer should be wrapped in a woollen rag. The screws and nuts securing the different connections and cables should be examined occasionally, as they frequently work loose through the vibration.

Attention to Brushes and Commutator.—The brushes and commutator are the most troublesome parts of a dynamo, and require most attention. To keep them in a satisfactory working condition, the main thing to be guarded against is the production of sparking at the brushes. If care be taken in the first instance to properly adjust the brushes to their setting marks, and their pressure upon the commutator, and afterwards to attend to the lead as the load varies, so that little or no sparking occurs, and to keep the brushes and commutator free from dirt, grit, &c., and excessive oil, the surface of the commutator will assume a dark burnished appearance, and all wear will practically cease. Under these circumstances the commutator will run cool, and free from sparking, and will give very little trouble. In order to maintain these conditions it will only be necessary to see that the brushes are properly trimmed and fed forward to their setting marks, as described above, as they wear away, and that the commutator is occasionally polished with the finest emery cloth. If, on the other hand, the pressure of the brushes upon the commutator is too great, or their adjustment is faulty, or the commutator is allowed to get into a dirty condition, sparking will inevitably result, and, if not at once attended to and remedied, the brushes will quickly wear away, and the surface of the commutator will be destroyed. If this condition of things is allowed to continue, matters will rapidly get worse. In the earlier stages, the surface of the commutator will become roughened or scored, resulting in jumping of the brushes, and increased sparking; in the later stages, the commutator will become untrue and worn into ruts, and owing to the violent sparking which takes place through this circumstance, the machine will quickly be rendered useless for practical purposes. When once started, the only way to remedy this condition of things is to repolish the commutator and readjust the brushes, as directed above. If the commutator is merely scored, a smooth file applied while the armature is revolving, with a final polishing with coarse and fine emery cloth, will generally put things into a satisfactory condition. If, however, the commutator is worn into deep ruts, or is untrue, nothing short of putting the armature in the lathe, and re-turning the commutator, will make a good job of it. When carbon brushes are used, a little extra special attention should be given in keeping the commutator perfectly clean, otherwise it is liable to heat up through short circuits, caused by carbon dust lodging between the segments. When carbon brushes are working properly, the fact is indicated by a uniform greyish tinge being imparted to the commutator, with a total absence of heating or sparking of any description. If the surface of the commutator assumes a mottled or streaky appearance, accompanied by small sparks flashing from segment to segment, it is advisable to slow down the machine and clean up the commutator at once. When either metal or carbon brushes are used, the surface of the commutator is bound in course of time to undergo a certain amount of wear, even when the greatest care is taken to reduce sparking. In order to prevent this wear giving rise to ruts or ridges upon the surfaces of the commutator, it is advisable to shift the brush-holders and brushes upon the rocker arm, if this is possible, from time to time. The unequal wear of the commutator may also be prevented by so arranging the brushes carried by one arm of the rocker that they cover the gaps between the brushes carried by the other arm of the rocker. The armature spindle or shaft is also given a little end play in order to prevent this grooving.

Lubricant on Commutator.—In most cases it will be found that a little lubricant is needed on the commutator in order to prevent cutting of the latter by the brushes, and this is especially the case when hard strip brushes are used. The quantity of oil so used should be very small—a few drops smeared upon a piece of clean rag, and applied to the commutator while running, being quite sufficient. It is advisable to use mineral oil, such as vaseline, or any other hydro-carbon. Animal or vegetable oils should be avoided, as they have a tendency to carbonise, and thus cause short-circuiting of the commutator, with attendant sparking.

Trimming Brushes.—At certain intervals, according to the care taken to reduce sparking, and the length of time the machine runs, the brushes will fray out or wear unevenly, and will therefore need trimming. They should then be removed from the brush-holders, and their contact ends or faces examined. If not truly square, they should be filed or clipped with a pair of shears, the course of treatment differing with the type of brush. If metal strip brushes, the feathered-out ends should be clipped square with a pair of shears, the ends thoroughly cleaned from any dirt or carbonised oil, and replaced in their holders. Gauze and wire brushes require a little more attention. When their position on the commutator has been well adjusted and looked after, so that little or no sparking has taken place, it will generally be only found necessary to wipe them clean, and clip off the fringed edges and corners with the shears, or a pair of strong scissors. If, however, the machine has been sparking, the faces will be worn or burnt away, and probably fused. If such is the case, they will need to be put in the filing clamp and filed up square and true, as directed above. If the contact faces of the brushes are very dirty and covered with a coating of carbonised oil, &c., it will be necessary to clean them with benzoline or soda solution before replacing. The handiest way of trimming carbon brushes, or of bedding a complete new set of metal brushes, is to bind a piece of emery cloth or sand paper, face outwards, around the commutator after the current has been shut off, and then mount the carbon or metal brushes in the holders, adjusting the tension of the springs so that the brushes bear with a moderately strong pressure upon the emery cloth or sand paper. Then let the machine run slowly until the ends of the brushes are ground to the proper form. Care should be taken, however, that the carbon or metal dust given off does not get into the commutator connections or armature windings, or short circuiting will result. If it becomes necessary, through sparking or other causes, to trim the brushes while the machine is working, one brush at a time should be removed from the holders. The brush to be removed should first be raised carefully from the commutator; then, if excessive sparking or heating occurs, the brush should be let down again, and the tension of the springs of the brushes temporarily increased until the brushes are trimmed. This of course only applies to machines provided with at least two brushes to each set. If only one brush is provided, the machine must be stopped before the brushes can be trimmed.

Shutting down Dynamo.—When shutting down a machine, the load should first be gradually reduced, if possible, by easing down the engine; then, when the machine is supplying little or no current, the main switch should be opened. This reduces the sparking at the switch contacts, and prevents the engine racing. When the voltmeter almost indicates zero, the brushes should be raised from contact with the commutator. This prevents the brushes being damaged in the event of the engine making a backward motion, which it often does, particularly when it is a gas-engine. On no account, however, should the brushes be raised from the commutator while the machine is generating any considerable voltage; for not only is the insulation of the machine liable to be damaged by this proceeding, but in the case of large shunt dynamos an exceedingly violent shock is liable to be administered to the person lifting the brushes. When the dynamo is at rest, or only revolving slowly, and the brushes are raised from the commutator, the latter should be cleaned up, if this is necessary. In dusty places, such as flour mills, sugar works, cement works, &c., it will probably be necessary to clean off the commutator with benzoline, and finally with finest emery cloth, at the end of every run. In places free from dust, it will only be necessary to wipe the revolving surface perfectly clean, or until it will not soil a white rag, and occasionally to apply a little fine emery cloth before stopping. When the machine is stopped it should be thoroughly cleaned up. The armature should be dusted with a pretty stiff brush from any adherent copper dust, dirt, &c., and the other portions of the machine should be thoroughly cleaned with linen rags. Waste should not be used, as it is liable to leave threads, fluff, &c., on the projecting parts, terminals, and other parts of the machine, and on the windings of the armature, which is very difficult to remove. The brushes should be examined, and if necessary trimmed and adjusted, and all terminals, screws, bolts, &c., carefully cleaned and screwed up ready for the next run. The brush-holders should receive special attention, as when dirty they are liable to stick and cause sparking. All dirt and oil should be removed from the springs and contacts, and pivots and other working parts. It is advisable at stated intervals to entirely remove the brush-holders from the rocker arms, and give them a thorough clean up, by taking them to pieces, and cleaning each part separately with emery cloth and benzoline or soda solution. Another point to which particular attention should be given is the cleaning of the brush rocker. This being composed wholly of metal, and the two sets of positive and negative brushes being only separated from it by a few thin insulating washers, it follows that if any copper dust given off by the brushes is deposited in the neighbourhood of these washers, there is considerable liability for a dead short circuit of the machine to occur, by the dust bridging across the insulation. These particular parts should therefore be kept scrupulously clean, and free from any conducting matter. It is a good plan, when the machine has been thoroughly cleaned up and all connections made secure, to occasionally test the insulation of the different parts and also that of the entire machine from earth with an Ohmeter or Wheatstone Bridge. If a record is kept of these tests, any deterioration of the insulation of the machine can at once be detected, localised, and remedied before it has got far enough to cause a breakdown. As a means of protecting the machine from any moisture, dirt, &c., while standing idle, it is advisable to cover it up with a suitable waterproof cover.

CHAPTER XI.

FAULTS IN DYNAMOS.

NO matter how well designed and constructed a dynamo may be, it is liable at some period or other of its life to develop irregularities in its working which may either wholly or partially incapacitate it from performing its duties. The abnormal performance may arise from a variety of causes, some purely electrical, others purely mechanical, or to both in combination. It may be due to some simple defect which is at once apparent on a little inspection of the machine, or on the other hand it may have its origin in some obscure cause which may almost defy detection. In any case, the source of the trouble should be diligently and patiently sought for, and when located, the appropriate remedy, if any, applied as soon as possible.

Testing Battery and Galvanometer.—As in the detection of electrical faults in dynamos a testing battery and galvanometer are indispensable, a few words regarding the construction and use of the most suitable types may not be out of place. In regard to the battery, a few cells of any of the well-known types as used in bell and telephone work, such as the Leclanche, Dry, Daniell, &c., are suitable. In reference to the galvanometer, a lineman's detector, or any ordinary sensitive galvanometer, will answer the purpose. A form of testing battery and galvanometer, specially designed and constructed for this class of work, is illustrated in Fig. 72. The battery consists of a number of small Leclanche cells, each contained in a sealed ebonite case. The

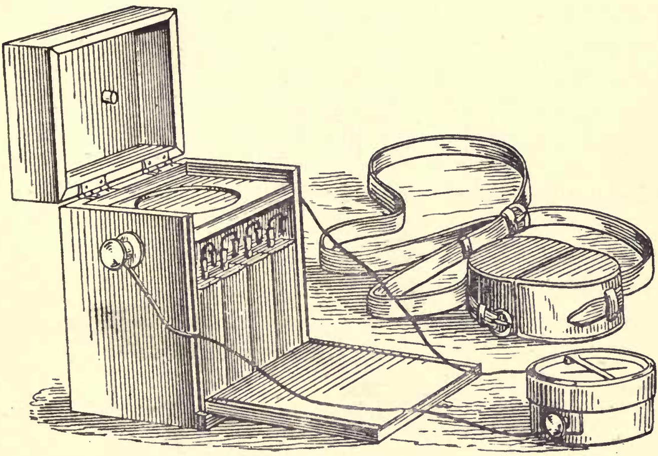

FIG. 72.

cells are connected in series, and contained in a hardwood outer case, which also contains the galvanometer when not in use. The positive and negative poles of the battery are connected to two brass terminals fixed upon the outside of the case, by means of which the battery may be connected to the galvanometer or the appliance, or circuit under test. The galvanometer consists of a pair of astatic magnetic needles, suitably arranged between a pair of bobbins or coils wound with fine insulated wire. The ends of the coils or bobbins are connected to two brass terminals, which are fixed upon two ebonite insulating blocks projecting through the brass case. When an electric current flows through the wire coils a magnetic field is created, and the needles are deflected to a greater or lesser degree in accordance with the strength of the current flowing in the coils. In testing for faults, two methods of connecting up the battery and galvanometer to the circuit under test are employed, these being termed the *conductivity* test and the *insulation* test respectively.

Testing for Conductivity.—In making this test, the instruments are connected as represented in

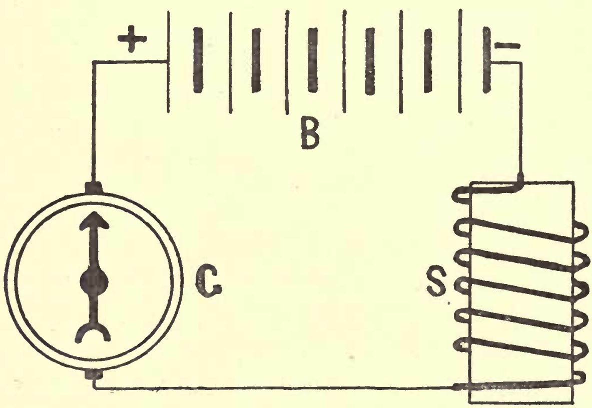

FIG. 73.

Fig. 73. B is the battery, G the galvanometer, and S is a coil of wire being tested for electrical continuity or conductivity. As will be seen, the positive pole +

of the battery is connected to one terminal of the galvanometer, and the other or negative pole is connected to one of the ends of the coil under test. The other terminal of the galvanometer is connected to the other end of the coil. If the connecting wires are making good electrical contact with the respective terminals, and the wire of the coil being tested is unbroken, the needle of the galvanometer will be deflected as soon as a closed circuit is made by the end of the coil coming into contact with the galvanometer terminal. If the wire of the coil is broken in some part, or the ends of the connecting wires do not make good electrical contact with the terminals, the needle will not be deflected. In order to prevent mistakes, it is advisable to test the battery and galvanometer connections and contacts by short circuiting or bringing the ends of the wires connecting the terminal of the galvanometer and negative pole of the battery together, before starting to test the circuit or coil. If the needle is deflected, the connections are all right; if undeflected, there is a bad contact somewhere which must be made good before the test can proceed.

Testing for Insulation.—The object of this test is to ascertain whether the insulation of a circuit or of the wire wound upon a metal spool or core, such as a magnet core, has broken down or is in good order. In making the test, the instruments and connections are arranged as shown in Fig. 74. The battery and galvanometer are connected to one another, as in the conductivity test described above. The unconnected terminal of the battery is connected to one end of the coil under test, the other end of the coil remaining free and unconnected. Some portion of the metal core, say the end, is then cleaned bright with a knife or emery cloth, and the unconnected terminal of the galvanometer is brought into contact with this bright or clean part of the core. If then some portion of the insulation of the wire has been abraded or destroyed, thus bringing the bare wire into contact with the metal core, as at A in the

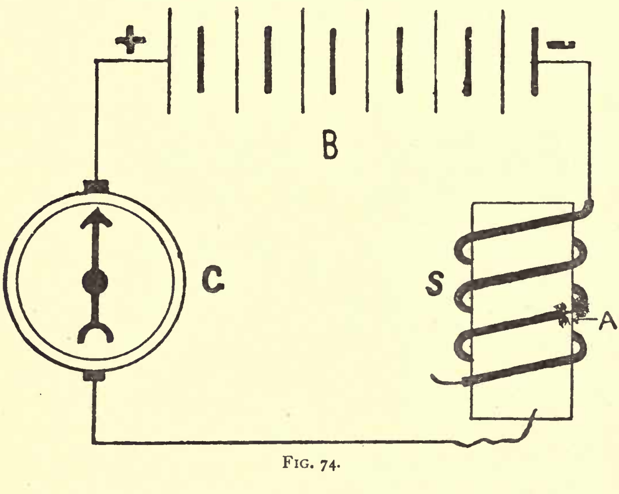

FIG. 74.

figure, the needle of the galvanometer will be deflected, since a closed circuit is formed through the core and wire. If, on the contrary, the insulation is perfect, the needle will be undeflected. It will thus be seen that in the conductivity test it is needful that the needle should be deflected to prove that all is right, whilst in the insulation test the converse holds good. If the needle is deflected, it proves that the insulation has broken down.

Faults in Dynamos.—The chiefest irregularities to which a dynamo is subject may be enumerated as follows:—

A. *Failure to excite.*
B. *Sparking at brushes.*
C. *Excessive heating.*
D. *Excessive noise or vibration.*
E. *Variation or decrease of speed.*
F. *Variation of voltage.*

Each of these irregularities may be due to a number of causes, acting either singly or in combination. A list of the defects or faults tending to produce a given irregularity is given under each heading when the same is under consideration in the succeeding paragraphs, and it will be necessary to test for each in turn until the true defect or fault producing the abnormal performance is located.

A. **Failure to Excite.**—If, when a reasonable time has elapsed, the machine (shunt, series, or compound) fails to excite, the following defects or faults should be sought or tested for in the order given, until the machine excites:—

(1.) Brushes out of neutral points.
(2.) Defective contacts.
(3.) Hand regulator incorrectly adjusted.
(4.) Incorrect connections.
(5.) Insufficient speed.
(6.) Open circuits.
(7.) Short circuits or heavy loads in external circuit.
(8.) Insufficient residual magnetism.

(9.) Reversed magnetism in fields.
(10.) Field coils acting in opposition.
(11.) Short circuits in dynamo.

A (1.) *Brushes out of Neutral Points.*—The first point to be observed, if the machine fails to excite, is the position of the brushes upon the commutator. If these are not on or near the neutral points, the whole of the E. M. F. of the armature will not be utilised, and will probably be insufficient to excite the machine. The correct positions for the brushes have already been described in Chapter X. (Running Dynamos). If in doubt as to the correct positions, the brushes should be rotated by means of the rocker into various points on the commutator, sufficient time, say five minutes, being given the machine to excite before moving them into a new position.

A (2.) *Defective Contacts.*—If the different points of contact of the connections of the machine are not kept thoroughly clean and free from oil, &c., it is probable that such resistance will be interposed in the path of the exciting current as to prevent the machine building or exciting. It may be remarked that the battery and galvanometer is not a decisive test for this fault, as the needle may be deflected through a resistance, due to a bad contact, much too great to allow of the small E. M. F., generated on first starting the machine, to send a current sufficiently great to build the machine. Each of the contacts should therefore be examined, and cleaned, and screwed up tight. The chief point to which attention should be given is the contact faces of the brushes and surface of the commutator. These are very frequently covered with a slimy coating of oil and dirt, which is quite sufficient to prevent the machine exciting. The brushes and commutator should be cleaned up as directed in Chapter X. (Running Dynamos).

A (3.) *Hand Regulator incorrectly adjusted.*—Shunt and compound wound machines are very frequently provided with hand regulators for inserting or removing resistance into the field circuit. When such is the case, it is possible the resistance in circuit may be too great to allow of the necessary strength of exciting current passing through the field windings. Therefore, in all cases before starting, remove by cutting out or short circuiting the whole of the resistance coils from circuit. The field coils of series machines are sometimes provided with short circuiting switches or resistances arranged to shunt the current across the field coils. In this case there may not be sufficient resistance in circuit, and therefore almost the whole of the exciting current will be shunted across in place of passing through the field coils. The remedy in this case is to open the switch completely, or, if this cannot be effected, to cut in sufficient resistance to enable sufficient current to pass through the field windings to excite the machine.

A (4.) *Incorrect Connections.*—When the machine is first erected, the failure to build may proceed from incorrect connections. The whole of these latter should therefore be traced or followed out, and compared with the diagrams of field and dynamo connections given in Figs. 44 to 59.

A (5.) *Insufficient Speed.*—In shunt and compound dynamos there is a certain *critical* speed below which they will not excite. If the normal speed of the machine is known it can at once be seen whether the failure to build arises from this cause, by measuring the speed of the armature with a speed indicator. In all cases it is advisable, if the machine does not excite in the course of a few minutes, to increase the speed to a certain extent. As soon as the voltage rises, the speed may be reduced to its normal value.

A (6.) *Open Circuits.*—The manner in which the different types of machines are affected by *open circuits* is dependent upon the class of machine. In the shunt machine it is necessary to have the external circuit open before it will build, whilst in the series machine it is needful to have it closed under like circumstances. Open circuits are most likely to occur in (*a*) Armature circuit; (*b*) Field circuit; (*c*) External circuit.

(*a*) *Open Circuit in Armature.*—The localisation and repair of faults in this circuit are described in Chapter XII. (Faults in Armatures). When the open circuit is due to the brushes not making good contact with the commutator, simple examination generally reveals the defect, which may be remedied as directed in A (2) (Defective Contacts).

(*b*) *Open Circuit in Field Circuit.*—This may be caused by bad contacts at the terminals, or broken connections, or fracture of the coil windings. Nothing but rigid inspection and testing of the entire field circuit will locate the fault. If the machine is shunt wound, it may occur in the hand regulator through a broken resistance coil or bad contact. Very frequently the fault occurs in the connecting wires leading from the machine to the hand regulator fixed upon the switchboard, or in the short wires connecting the field coils to the terminals or brushes. The insulation of a wire will sometimes hold the two ends of a broken wire together so as to defy any but the most careful inspection or examination; therefore, in order to avoid loss of time, it is advisable to disconnect the wires if possible, and test each separately for conductivity with a battery and galvanometer connected, as in Fig. 73. If the fault is not located in the various connections, the magnet coils should be tested with the battery and galvanometer coupled up as in Fig. 73, care being first taken to disconnect the ends of each of the coils. A faulty coil will not show any deflection of the galvanometer. Having located the faulty coil, the discontinuity or break should be searched for and rectified. In the shunt coils of shunt and compound dynamos, and these are most liable to this defect, the break invariably occurs at the point where the wire passes through the flanges of the spool or bobbin. In most cases a little of the wood or metal of which the flange is made can be gouged or chipped out, and a new connecting wire soldered on to the broken end of the coil without much difficulty. If it is necessary to take the magnets apart at any time, great care should be taken in putting them together again to wipe all faces perfectly clean, and screw up firmly into contact, the connections of the coils being made as before taken apart. If the faulty coil cannot be repaired quickly, and the machine is urgently required, the coil may be cut out of circuit entirely, or short circuited, and the remaining coils coupled up so as to produce the correct polarity in the pole pieces.

In this case, however, as the coils are liable to heat up to a greater extent than formerly, owing to the increased current, it is advisable to proceed cautiously in starting the dynamo, in case the temperature exceeds a safe limit. If this occurs, a resistance may be put in circuit with the field coils, or the speed of the dynamo reduced.

(*c*) *Open Circuit in External Circuit.*—Series wound machines are only affected by this occurrence. If the disconnection is complete, the fault may readily be located by the battery and galvanometer coupled up as in Fig. 73. If only partial, however, this fault is very elusive, for the reasons mentioned in A (2) (Defective Contacts). If the external circuit tests out apparently all right, and no defective contacts are apparent in any part of the machine, and all short circuiting switches, &c., are cut out of circuit, and the machine still refuses to excite, short circuiting the terminals of the machine should be tried. This should be effected very cautiously, especially if a high tension machine. It is advisable to have, if possible, only a portion of the load in circuit, and the short circuit should be effected as shown in Fig. 75 AB. The short circuit may be made by momentarily bridging across the two terminals of the machine with a single piece of wire. As this, however, is liable to burn the terminals, a better plan is to fix a short piece of scrap wire in one terminal, and then with another piece of insulated wire make momentary contacts with the other terminal and the short piece of wire. If the machine excites, it will be at once evident by the arc which occurs between the two pieces of wire. As the voltage of a series machine when induced to build in this manner generally rises very rapidly, great care should be taken that the contact is at first only momentary, merely a rubbing or scraping touch of the wires. The contact may be prolonged if the machine does not excite at the first contact. Compound wound machines can often be

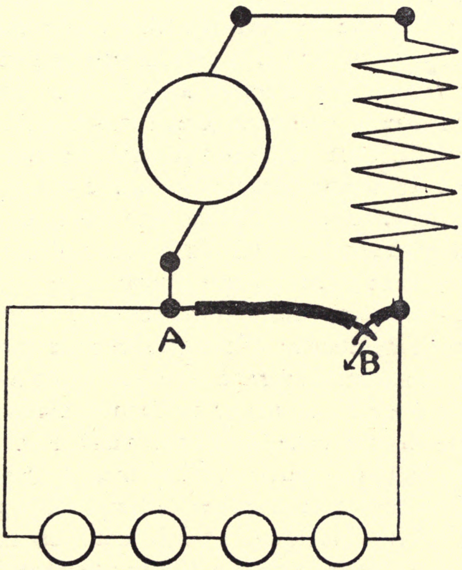

FIG. 75.

made to build quickly by short circuiting their terminals in this manner.

A (7.) *Short Circuits or Heavy Load in External Circuit.*—A shunt machine will not excite under these circumstances, for the reason that practically the whole of the current generated in the armature passes direct to the external circuit, and the difference of potential between the shunt terminals is practically nil. If it is suspected that the failure to excite arises from this cause, the main leads should be taken out of the dynamo terminals, when, if due to this cause, the machine will excite. When the machine is compound or series wound, a fault of this description causes the machine to overload and blow the fuses. If due to overload, this latter should be removed as directed in B (4) (Overload of Dynamo).

A (8.) *Insufficient Residual Magnetism.*—This fault is not of frequent occurrence, and it is almost impossible for it to take place if the field magnets are of cast-iron. It always occurs when the dynamo is a new one, or when the field magnets have been taken apart for repairs, &c. It may be remedied by passing the current from a few storage cells, or another dynamo, for some time in the proper direction through the field coils. If a heavy current, such as is obtainable from a storage battery, is not available, and the machine is shunt or compound wound, a few Leclanché or dry cells, arranged as in Fig. 76, will generally effect the purpose. The flexible "lead" (L) of the dynamo (D) is disconnected from the positive terminal of the machine, and is connected to the negative or zinc pole of the battery (B), the other or positive carbon pole being connected to the terminal, from which the lead was removed, and shunt circuit (S). As thus arranged, it will be seen that the battery (B) is in series with the armature and shunt circuit, and therefore its E. M. F. will be added to any small E. M. F. generated in the armature. When the machine is started, the combined E. M. F.s will probably be able to send sufficient current through the shunt to excite the machine. As the voltage rises and the strength of the current in the shunt windings increases, the flexible lead may be again inserted into the terminal from which it was removed.

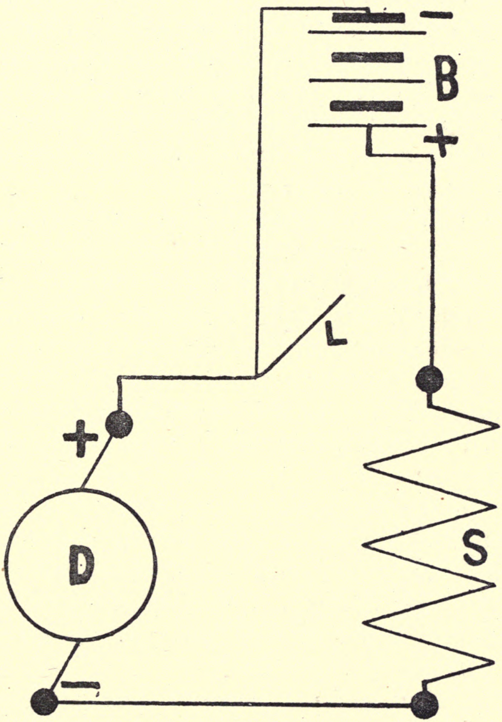

FIG. 76.

The battery will thus be short circuited, and may be cut out of circuit without any danger of breaking the shunt circuit, and thus causing the machine to demagnetise.

A (9.) *Reversed Magnetism in Fields.*—This also is a fault of infrequent occurrence. It may be caused by the proximity of other dynamos, but is generally due to reversed connections of the field coils. Under such conditions the field coils tend to produce a polarity opposed to the magnetisation to which they owe their current, and therefore the machine will refuse to excite until the field connections are reversed, or a current is sent from another dynamo or a battery through the field coils in a direction to produce the correct polarity in the pole pieces.

A (10.) *Field Coils acting in Opposition.*—This may occur when the dynamo is a new one, or the coils have been removed for repairs. It may be caused either through the coils having been put on the field cores the wrong way, or through incorrect coupling up. Under these circumstances, the dynamo, if bi-polar, will fail to excite; and if multipolar, poles will be produced in the yokes, &c. It may be remedied by removing one of the coils from the core and putting it on the reverse way, or by reversing its connections. The connections of all the coils should be verified by applying Professor Jamieson's rule given on page 21. The manner of coupling up the coils of the different types of field magnets will be understood by reference to Figs. 52 to 59. In compound dynamos it sometimes happens that the machine will excite properly, but that the series coils tend to reverse the polarity of the dynamo, thus reducing the voltage as the load upon the machine increases. This may be detected when the machine is loaded by short circuiting the *series coils*, *not* the *terminals*. If the voltage rises in doing this, the series coils are acting in opposition to the shunt coils, and the connections of the *series coils* must be reversed.

A (11.) *Short Circuits in Dynamo.*—A dynamo may refuse to excite through some portion of its windings or connections being short circuited, for the reason that the field magnets are deprived of the necessary current required for building the machine. Short circuits most frequently occur in (*a*) Terminals; (*b*) Brush-holders; (*c*) Commutator; (*d*) Armature coils; (*e*) Field coils.

(*a*) *Short Circuits in Terminals.*—The terminals of the various circuits of the machine are liable to be short circuited, either through metallic dust bridging across the insulation, or through the terminals making direct contact with the frame of the machine. The various terminals should be examined, and if the fault cannot be located by inspection, they should each be disconnected from their circuits and tested with a battery and galvanometer arranged as in Fig. 77. B is the battery, one pole of which is placed in contact with the frame of the machine at a point which has previously been well scraped and cleaned; the other pole is connected to one of the galvanometer terminals as shown. The other terminal of the galvanometer is connected to each of the dynamo terminals (T T) under test in turn. If a deflection of the needle is produced when the galvanometer terminal is in contact with either, the terminals are in contact with the frame, and they should then be removed, and the fault repaired by additional insulation or by reinsulating.

(*b*) *Short Circuits in Brush-holders.*—As previously mentioned, the brush-holders are liable to be short circuited through the rocker by metallic dust lodging in the insulating washers. These points should therefore be examined and cleaned, and the two sets of brush-holders tested for short circuits between them. To test the brush-holders, the brushes should be

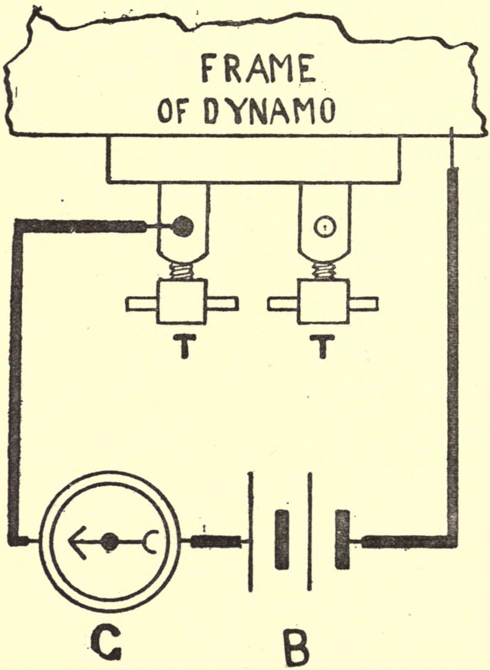

FIG. 77.

raised from contact with the commutator by means of the hold-off catches, and all connecting cables removed. The galvanometer and battery should then be coupled up, as in Fig. 74, and one terminal of the galvanometer connected to one set of brushes, and the other set placed in connection with the unconnected terminal of the battery. If the needle is deflected when thus connected, the brush-holders are short circuited through some point, when they should be taken out of the rockers and the fault repaired.

(*c*) *Short Circuits in Commutator;* (*d*) *Short Circuits in Armature Coils.*—The localisation and repair of faults in these parts of a dynamo are fully described in Chapter XII. (Faults in Armatures).

(*e*) *Short Circuits in Field Coils.*— When short circuits occur in the field coils or circuit, the machine as a rule refuses to excite. The short circuit may be in the terminals or connections, and these should first be examined and tested as described above (*a*). When in the field coils, the fault may be detected by measuring the resistance of each of the coils with an Ohmeter or Wheatstone Bridge. The faulty coils will show a much less resistance than the perfect coils. The fault may also be discovered and located by passing a strong current from a battery or another dynamo through each of the coils in turn, and observing the relative magnetic effects produced by each upon a bar of iron held in their vicinity. Some series dynamos are provided with a resistance, arranged in parallel or shunt with the field coils, to divert a portion of the current therefrom, and thus regulate the output. When making a series dynamo excite, all resistances and controlling devices should be temporarily cut out of circuit by opening the shunt circuit. Series machines have frequently a switch which short circuits the field coils. Care should be taken that this is open, or otherwise the machine will not excite.

B. **Sparking at Brushes.**—In all good dynamos there are certain positions upon the commutator for the brushes at which there will be absolutely no sparking so long as the commutator is kept clean and in good condition. In other dynamos, badly designed or constructed, sparking occurs at all positions, no matter where the brushes are placed, and in such dynamos it is therefore impossible to prevent sparking at the brushes, no matter how well they are adjusted. When sparking occurs at the brushes of a good dynamo, two kinds may generally be distinguished by the practised eye, viz., those sparks due to bad adjustment of the brushes, generally of a bluish colour, small when near the neutral points, and increasing in violence and brilliancy as the brushes recede from the correct positions upon the commutator; and those due to dirty and neglected state of the commutator and brushes, these being distinguished by a reddish colour and a spluttering or hissing. When due to this last-mentioned cause, it is impossible to suppress the sparking until the commutator and brushes have been cleaned up. In the former case, the sparks will disappear as soon as the brushes have been rotated into the neutral points. Another class of sparks appear when there is some more or less developed fault, such as a short circuit, or disconnection in the armature or commutator. These are similar in character to those produced by bad adjustment of the brushes, but are distinguished from the latter by their not decreasing in violence as the brushes are rotated towards the neutral points. Having distinguished the classes of sparks which appear at the commutator of a dynamo, it remains to enumerate the causes tending to produce sparking. These are :—

(1.) Bad adjustment of brushes.
(2.) Bad condition of brushes.
(3.) Bad condition of commutator.
(4.) Overload of dynamo.
(5.) Loose connections, terminals, &c.
(6.) Disconnections in armature circuit.
(7.) Short circuits in armature circuit.
(8.) Short circuits or disconnections in field magnet circuit.

B (1.) *Bad Adjustment of Brushes.*—When sparking is produced by bad adjustment of the brushes, it may be detected by rotating or shifting the rocker, by the indication that the sparking will vary with each movement. To obtain good adjustment of the brushes, it will be necessary to rock them gently backwards and forwards, as directed in Chapter X., until a position is found in which the sparking disappears. If a position cannot be found at which the sparking disappears, it is probable that the brushes are not placed diametrically apart upon the commutator, or that the neutral points are not situated in their true theoretical positions upon the commutator through some defect in the winding, &c. In this last-mentioned case, the brushes may be strictly adjusted to their theoretically correct positions before starting the machine; then, when the machine is started and the load put on, violent sparking occurs, which cannot be suppressed by shifting the rocker. If, however, one set of brushes only is observed, it will generally be found that, at a certain position, the sparking at the set of brushes under observation ceases or is greatly reduced, while sparking still occurs at the other set. When this position is found, the rocker should be fixed by the clamping screw, and the brushes of the other set at which sparking is still occurring adjusted by drawing them back or pushing them forward in their holders until a position is found at which the sparking ceases, at which they should be fixed. Correct position of the brushes upon the commutator and the suppression of sparking is a matter of great importance, and any time spent in carefully adjusting will be amply repaid by the decreased attention and wear of the brushes and commutator.

B (2.) *Bad Condition of Brushes.*—If the contact faces of the brushes are fused or covered with carbonised oil, dirt, &c., there will be bad contact between the brushes and commutator, and consequently great heating and sparking. Simple examination will generally reveal whether this is the case. The remedy is to remove the brushes, one at a time if the machine is running, clean, file if necessary, trim, and readjust. If the brushes are exceedingly dirty, or saturated with oil, it will be necessary to clean them with turpentine, benzoline, or soda solution, before replacing.

B (3.) *Bad Condition of Commutator.*—If the surface of the commutator is rough, worn into grooves, or eccentric, or has one or more segments loose, or set irregularly, the brushes will be thrown into vibration, and sparking will result. A simple examination of the commutator will readily detect these defects. The remedy for a rough commutator is to file it up while running with a dead-smooth file, afterwards polishing with finest emery cloth. If the commutator is untrue, the fact will be indicated when the machine is slowed down by a visible excentricity, or by holding the hand, or a stick in the case of high tension machines, against the surface while revolving, when any irregularity or excentricity will be apparent by the vibration or movement of the stick. The only remedy for an excentric commutator is to re-turn it as directed in the succeeding paragraph. Loose or high or low segments may be detected by the same means. The remedy for high segments is to tap them gently down with a small hammer or mallet, and if possible tighten up the clamping cones at the ends of the commutator. If it is impossible to hammer the segments down, they should be filed down level with the rest of the commutator, or the commutator re-turned. For low segments, the only remedy is to pull out the segments as directed in Chapter XII. (Faults in Armatures), or turn commutator down to their level.

Re-turning Commutator.—In re-turning the commutator, the armature should first be carefully taken out of the armature chamber, avoiding knocks or blows of any kind. The whole of the windings should then, in order to prevent any particles of metal finding their way on to the surface of the armature at the time the commutator is being turned, be entirely wrapped in calico or canvas before the armature is put into the lathe. The armature should on no account be rolled upon the floor, or subjected to blows or knocks while being put into the lathe, the winding is liable to be ruined if this takes place.

In re-turning the commutator, a sharp-pointed tool should be used with a very fine feed. A broad-nosed tool ought not to be used, as it is liable to burr over the segments. After turning, the commutator should be lightly filed up with a dead-smooth file, and finally polished with coarse and fine emery cloth. After the commutator has been turned and polished, the insulation between the segments should be lightly scraped with the tang of a small file to remove any particles or burrs of metal which may be likely to short circuit the commutator. The points where the armature wires are soldered to the lugs should also be carefully cleaned with a brush from any adherent copper dust, and should then receive a coat or two of shellac varnish. While the commutator is being turned, care should be taken that the setting marks for the adjustment of the brushes are not turned out if these are present. The same care should be used in putting the armature back into the armature chamber as was used in taking it out, otherwise the insulation is liable to be seriously damaged.

B (4.) *Overload of Dynamo.*—It may happen through some cause or other that a greater output is taken from the machine than it can safely carry. When this is the case, the fact is indicated by excessive sparking at the brushes, great heating of the armature and other parts of the dynamo, and possibly by the slipping of the belt (if a belt-driven machine), resulting in a noise. The causes most likely to produce overload are:—(*a*) Excessive voltage; (*b*) Excessive current; (*c*) Reversal of polarity of dynamo; (*d*) Short circuits or grounds in dynamo, or external circuits.

(*a*) *Excessive Voltage.*—This will be indicated by the voltmeter, and by the brightness of the pilot lamp. It may be caused either by excessive excitation of the field magnets, or by excessive speed. In the former case, resistance should be introduced into the field circuit to diminish the current flowing therein if a shunt machine; or if a series machine, a portion of the current should be shunted across the field coils by means of a resistance arranged in parallel with the series coils; or the same effect may be produced in both cases by reducing the speed of the armature if this is possible. If due to excessive speed, which will be indicated by a speed indicator, the natural remedy is to reduce the speed of the motor driving the dynamo, or, if this is not possible, insert resistance into the dynamo circuit, as described above.

(*b*) *Excessive Current.*—This will be indicated by the ammeter. If the dynamo is supplying arc lamps, the excessive current may possibly be caused by the bad feeding of the lamps. If this is the case, the fact will be indicated by the oscillations of the ammeter needle, and by the unsteadiness of the light. If incandescent lamps are in circuit, the fault may be caused by there being more lamps in circuit than the dynamo is designed to carry. Under such circumstances, another dynamo should be switched into circuit in parallel, or, if this is not possible, lamps should be switched off until the defect is remedied. When electro-motors are in circuit, sparking frequently results at the dynamo commutator, owing to the fluctuating load. In such cases the brushes should be adjusted to a position at which the least sparking occurs with the average load.

(*c*) *Reversal of Polarity of Dynamo.*—When compound or series wound dynamos are running in parallel, their polarity is occasionally reversed while stopping by the current from the machines at work. Under such conditions, when the machine is again started, the E. M. F. of one is added to that of another, or the machines are connected in series, so that a closed circuit is formed, and as a consequence an enormous current results. Before the machine can be again coupled in parallel, it will be necessary to send a current through the field coils in the reverse direction.

(*d*) *Short Circuits or Grounds in Dynamo or External Circuits.*—A dynamo is liable to be overloaded through bad insulation of the dynamo or external circuits, resulting in a considerable leakage of current, in which case the ammeter will probably not indicate the fact. To ascertain if this is the case, connect a piece of insulated wire to one of the terminals of the machine while running, and then make short momentary contacts with the ground through a water pipe, or frame of the dynamo, or other body in good connection with the earth. If a flash occurs, it proves that the insulation is defective somewhere. This test should be applied to each of the terminals in turn. The fault should next be located by taking the mains to the external circuit out of the terminals of the machine, and again testing as before. If a flash again occurs, it proves that the defect exists in the dynamo, which should be stopped, and the terminals, &c., tested with a battery and galvanometer, as directed in A (11) (Short Circuits in Dynamo). It must be clearly understood that a fault of this description is just as likely to occur in the external circuit, and therefore, if after removing the mains from the terminals of the machine, and again testing, the flash disappears, it may be taken that the fault is in the external circuit, which should be tested in a similar manner to the dynamo.

B (5.) *Loose Connections, Terminals, &c.*—When any of the connecting cables, terminal screws, &c., securing the different circuits are loose, sparking at the brushes, as a rule, results, for the reason that the vibration of the machine tends to continually alter the resistance of the various circuits to which they are connected. When the connections are excessively loose, sparking also results at their points of contact, and by this indication the faulty connections may be readily detected. When this sparking at the contacts is absent, the whole of the connections should be carefully examined and tested as in A (2) (Defective Contacts).

B (6.) *Disconnections in Armature Circuit.*—If there is a broken circuit in the armature, as sometimes happens, through a fracture of the armature connections, &c., there will be serious flashing or sparking at the brushes, which cannot be suppressed by adjusting the rocker. As a rule it results in the production of "flats" upon one or more bars of the commutator. If it is impossible to stop the machine, the sparking may be much reduced by placing one of the brushes in each set a little in advance of the others, so as to bridge across the disconnection. If the machine is only provided with one brush on each side of the commutator, a bit of copper wire may be fixed in each holder, so as to project slightly in front of the brushes, and thus bridge over the broken circuit. The localisation and repair of this fault is described in Chapter XII. (Faults in Armatures).

B (7.) *Short Circuits in Armature Circuit.*—This fault is indicated by sparking at the commutator, and in bad cases by an excessive heating of the armature, dimming of the light, and slipping of the belt, and in the case of drum armatures by a sudden cessation of the current. The localisation and repair of the different classes of short circuits is referred to in the succeeding chapter (Faults in Armatures).

B (8.) *Short Circuits or Disconnections in Field Magnet Circuit.*—Either of these faults is liable to give rise to sparking at the commutator. If one of the coils is short circuited, the fact will be indicated by the faulty coil remaining cool while the perfect coil is overheated. The fault may arise through some of the connections to the coils making contact with the frame of the machine or each other. To ascertain this, examine all the connections, and test with a battery and galvanometer in the manner described in A (2), A (6), A (11). A total disconnection in one or more of the field coils may readily be detected by means of the battery and galvanometer. A partial disconnection is not, however, so readily discovered, for the reason that the coil wires may be in sufficiently close contact to give a deflection of the galvanometer needle. The only methods of detecting this fault is by measuring the resistance of the coils with an Ohmeter or Wheatstone Bridge, or by placing an ammeter in circuit with each coil in turn, and comparing the amount of current flowing in each. If the short circuit is not accessible, the only way to remedy the fault is to re-wind the coil, and the same applies to a disconnection if in the interior of the coil.

C. **Excessive Heating.**—The excessive heating of the constituent parts of a dynamo is probably the most common and at the same time the most annoying fault which arises in the working of the dynamo. It may be due to various causes, electrical or mechanical; and may occur in any one or more of the component parts of the dynamo:—

(1.) Connections.
(2.) Armature, commutator, brushes.
(3.) Field magnets.
(4.) Bearings.

It may be detected by applying the hand to the different portions of the machine if low tension, or a thermometer if high tension, as directed in Chapter X. (Running Dynamos), and also by a smell of overheated insulation and paint or varnish. When this last indication is felt, it is advisable to stop the machine at once, otherwise the insulation is liable to be destroyed.

C (1.) *Heating of Connections.*—This may proceed from either or both (*a*, *b*) of the following causes:—

(*a*) *Excessive Current.*—The terminals and connections will be excessively heated if a larger current passes through them than they are designed to carry. This nearly always proceeds from an overload of the dynamo, and if this is rectified as directed in B (4) (Overload of Dynamo), the heating will disappear.

(*b*) *Bad Contacts.*—If the contacts of the different connections of the dynamo are not kept thoroughly clean and free from all grit, oil, &c., and the connections themselves are not tightly screwed up, great heating will result, and they may even be unsoldered.

C (2.) *Heating of Armature, Commutator, and Brushes.*—When excessive heating occurs in these portions of the dynamo, it may proceed from any of the following causes:—(*a*) Excessive current; (*b*) Heated bearings; (*c*) Short circuits in armature or commutator; (*d*) Moisture in armature coils; (*e*) Disconnections in armature coils; (*f*) Eddy currents in armature core or conductors.

(*a*) *Excessive Current.*—When the dynamo is overloaded, the temperature of the armature will rise to a dangerous extent, depending upon the degree the safe capacity of the machine is exceeded, and heavy sparking of the brushes will also result. If the overload is not removed as directed in B (4) (Overload of Dynamo), the insulation of the armature may be destroyed.

(*b*) *Heated Bearings.*—If the bearings are heated, the heat may be conducted along the armature shaft and core, thus giving rise to excessive heating of the armature. In this case the source of the heating may be located and remedied as directed in C (4) (Heated Bearings).

(*c*) *Short Circuits in Armature or Commutator.*—This fault results in sparking at the brushes, and in excessive heating of one or the whole of the armature coils, and even in the burning up of the latter if a bad case. When the armature is overheated, and the defect does not proceed from an overload or the causes mentioned below, the dynamo should be immediately stopped and tested for this fault as directed in Chapter XII. (Faults in Armatures).

(*d*) *Moisture in Armature Coils.*—The effect of this fault being to practically short circuit the armature, a heating of the latter results. In bad cases steam or vapour is given off. To remedy this fault proceed as in Chapter XII. (Faults in Armatures).

(*e*) *Disconnections in Armature Coils.*—This fault results in local heating of the armature, for the reason that resistance is interposed in the path of the current at the fracture. It always results in sparking at the brushes, and the heating being confined to the neighbourhood of the disconnection, this latter may easily be located by this indication, or by the methods described in Chapter XII. (Faults in Armatures).

(*f*) *Eddy Currents in Armature Core or Conductors.*—When the construction of the armature core and conductors does not fulfil the necessary conditions required for the prevention of eddy currents, such as the laminations not being sufficiently insulated or numerous enough, a great heating of the whole of the armature results, which may even extend to the bearings. There is no remedy for this defect other than the purchase of a new armature, or the entire reconstruction of the old. The fault may be detected by exciting the field magnets and running the machine on open circuit, with the brushes raised off the commutator for some time, when the armature will be found to be excessively heated.

C (3.) *Heating of Field Magnets.*—When the field magnets are found to be excessively heated, they should be tested for the following faults in the order given:—(*a*) Excessive exciting current; (*b*) Moisture in field coils; (*c*) Short circuits in field coils; (*d*) Eddy currents in pole pieces.

(*a*) *Excessive Exciting Current.*—When the excessive heating arises from this cause, all the exciting coils will be heated equally. It may be due to excessive voltage, in the case of shunt dynamos; or to an overload in the case of compound and series dynamos. In either case it may be remedied by reducing the voltage or overload as directed in B (4) (Overload of Dynamo). If due to the coils being incorrectly coupled up, *i.e.*, coupled up in parallel in place of series, it will be necessary to rectify the connections or insert a resistance in series.

(*b*) *Moisture of Field Coils.*—As in the armature, the presence of damp or moisture in the field coils tends to decrease the insulation resistance, thus in effect producing a short circuit with its attendant heating. The fault may easily be detected by applying the hand to the field coils, when they will be found to be damp, and in addition steam or vapour will be given off where the machine is working. The fault may be remedied by drying and varnishing the coils as directed in "Moisture in Armature Coils."

(*c*) *Short Circuits in Field Coils.*—This fault is characterised by an unequal heating of the field coils. If the coils are connected in series, the faulty coil will be heated to a less extent than the perfect coils. If, on the other hand, they are connected in parallel, the faulty coil will be heated to a greater extent than the perfect coils. The faulty coil can thus be easily located by this indication, and also by measuring the resistance of each with an Ohmeter or Wheatstone Bridge.

(*d*) *Eddy Currents in Pole Pieces.*—This fault may be due to defective design or construction of the armature. Toothed core armatures are particularly liable to cause this fault, if the teeth and air gap are not properly proportioned. The defect may also be occasioned by variation in the strength of the exciting current. If due to this latter cause, it will be accompanied by sparking at the brushes. If a shunt dynamo, insert an ammeter into the shunt circuit, and note if the deflection is steady. If this is not the case, the variation in the current most probably proceeds from imperfect contacts thrown into vibration. These can be remedied as in A (2) (Defective Contacts).

C (4.) *Heating of Bearings.*—The heating of the bearings is of frequent occurrence in the working of dynamos, and is probably the most troublesome fault to which they are subject, as its origin is, as a rule, obscure. When the bearings heat excessively, so that the heat cannot be borne by the naked hand, and such simple remedies as the supply of fresh lubricant, or slacking back the caps of the bearings or the belt fails to remedy the trouble, the dynamo should be stopped, as it indicates something radically wrong. The use of water on heated bearings has been recommended, but its use is questionable. No doubt it cools the bearings for the time being, and allows of the machine being run for a short time longer ; but when the bearings are in such condition as to need the application of water, probably as much damage is done to the journals and liners, through scoring, &c., as more than counterbalances any slight gain secured through running the machine while the bearings are heated. Removing the lubricators, and flooding the bearings and journals with ordinary or castor oil, tends to reduce the heating; or the effect of sulphur mixed with oil, and applied *direct* to the bearings, after removing the lubricators, should be tried. If these remedies fail, the machine should be stopped, and the cause of the heating ascertained. As a rule, heating of the bearings is due to—(*a*) Defective lubrication or bad oil; (*b*) Journals too tight; (*c*) Belt too tight; (*d*) Dirt, grit, &c., in bearings; (*e*) Rough or badly fitted journals or bearings; (*f*) Bent or badly turned shaft; (*g*) End pressure of shaft against bearings; (*h*) Armature incorrectly placed in armature chamber; (*i*) Badly proportioned bearings; (*j*) Bearings out of line; (*k*) Conduction of heat from armature.

(*a*) *Defective Lubrication or Bad Oil.*—When the bearings heat up, first examine the lubricators to see that they are full, and that they feed the lubricant properly, and that none of the feed or waste oil passages are clogged. It is advisable to pass the end of a piece of wire down each of the passages occasionally to clear them. The quality of the oil supplied to the lubricators should be of the best mineral oil, perfectly clean and free from grit. It is advisable not to use the waste oil for the dynamo again; but if used, see that it is well filtered. In some instances, hot bearings, due to defective lubrication, have been remedied by cutting grooves obliquely in the face of the liners for the better circulation of the oil.

(*b*) *Journals too tight.*—If the caps of the bearings are screwed up too tight, the bearings are bound to heat up. As the armature spindle or shaft is not subjected to any reciprocal stresses, it is only needful to have the caps of the bearings screwed up hand tight. If the top brass does not bear upon the bottom brass, it may be necessary to scrape open the bearing a little, or insert a liner between the top and bottom brasses, until the spindle revolves freely by hand.

(*c*) *Belt too tight.*—Heating of the bearings may be due to too great a tension of the belt, caused either by an overload of the dynamo, or through too narrow a belt being used for the work, thus necessitating the dynamo being screwed up tightly upon the slides. When this is the case, the bearing next the pulley will be heated more than the other. The remedy is to reduce the load upon the dynamo, as directed in B (4) (Overload of Dynamo), or get a broader belt and pulley and run with some slack on the belt.

(*d*) *Dirt, Grit, &c., in Bearings.*—The presence of the smallest quantity of grit in the lubricant or bearings will result in great heating of the latter, and in scoring of the shaft and liners, if not removed quickly. The machine should be stopped if possible, and the caps of the bearings taken off and the armature taken out of the bearings, and the latter carefully cleaned and scraped up smooth. If the journals are scored to any extent, it will be necessary to put the armature in the lathe and carefully file them up with a dead-smooth file before replacing. If the machine cannot be stopped at once, the lubricators should be made to feed very fast, or removed entirely, and the bearings continuously flooded with oil by means of an oil can until the machine can be conveniently stopped.

(*e*) *Rough or Badly Fitted Journals or Bearings.*—To ensure cool running, the journals should be perfectly smooth and true, and bear upon the surface of the liners throughout their entire length and width. To ascertain if this is the case, the caps of the bearings should be removed, and a little "marking," composed of red lead or other colouring matter and ordinary oil, rubbed upon the journals. The caps should then be replaced, and the nuts screwed up to working pressure, and the armature rotated a few times. The caps should then be again removed, and the armature taken out, and the bearings examined. If the journals are bearing all over the surface of the liners, the fact will be indicated by the marking being distributed equally all over. If this is not the case, the projecting portions of the liners, as indicated by the marking, should be carefully scraped up and the armature put back again, and the bearings tested from time to time until the journals bear all over as indicated by the marking being equally distributed all over the surface of the liners.

(*f*) *Bent or Badly Turned Shaft.*—A bent shaft can be detected by rotating it with the hand. If bent, it will "bind" at some portion of the revolution. If only slightly bent, the shaft should be placed in the lathe and carefully sprung back approximately straight, a light cut being taken off the journals to finally true it. The bearings will then need to be carefully refitted, as directed above. If badly bent, the only remedy is a new one. A badly turned shaft may be detected by means of the calipers and marking, as described above. If not truly circular, the marking will be unequally distributed over the *journals.*

(*g*) *End Pressure of Shaft against Bearings.*—This may be caused either by the shaft not being truly level, or through the belt not being truly aligned, or through there being no "end play." In the former case, carefully test the journals with a spirit-level, and pack up the dynamo or slide rails until perfectly level. If the belt does not run true upon the pulleys, it will be necessary to align the machine by moving it upon the sliding bedplate until the centre of the belt runs upon the centre of the pulley. If no end play exists, the shaft will be bound between the collars and the bearings, and the defect will be visible to the eye. The correct amount of end play required varies with the size of the dynamo and method of driving adopted. In direct driven dynamos, if the collars of the journals are clear of the ends of the bearings, no end play is needed. In belt-driven dynamos, it is necessary to have from one-eighth to three-eighths of an inch of end play. In all cases it may be ascertained if the correct amount of end play is present by running the dynamo and observing, when *slight* pressure is applied to one end of the shaft, if any end motion is produced. If no end motion is obtained, or a strong pressure is needed to obtain the latter, the face of the collar or end of the bearing against which the shaft bears should be filed or turned down, until the correct amount is obtained, when the machine is running.

(*h*) *Armature incorrectly placed in Armature Chamber.*—When the field magnet of a dynamo is excited, it has a tendency to attract the iron core of the armature. The direction and intensity of the attractive force varies with the type of field magnet and the position of the armature core in the armature chamber or bore. In vertical horse-shoe magnets of the over-type form (Fig. 53), if the armature is placed exactly in the centre of the armature chamber, there is a tendency for the armature to be attracted downwards, the intensity of the attraction varying with the strength of the field magnets. In large dynamos this attractive force may even amount to some thousands of pounds, and therefore, if the armature core is not placed in the armature bore in such position as to balance or nullify the attractive force, the bearings are liable to heat up through the excessive pressure brought to bear upon them. To counterbalance the attractive force, it is necessary in such dynamos to place the armature slightly above the centre of the armature chamber. In field magnets of the undertype form (Fig. 54), the attraction is in an upward direction, and therefore, as the weight of the core is lifted off the bearings, the latter are not so liable to heat up as is the case with the overtype form. In horizontal field magnets (Figs. 55, 56, and 57), the attractive forces act in opposite directions, and are therefore balanced; and in such dynamos the armature core may be placed exactly in the centre of the armature bore. A heating of the bearings is also liable to be occasioned through the attractive forces developed by the centre of the armature core not being parallel with the centre of the armature chamber or bore, or through the core being nearer one pole piece than the other. This may result from unequal wearing of the bearings, and therefore the bearings should either be re-lined or the bolt holes of the bearings readjusted, or the bearings packed up until the armature is correctly centred.

(*i*) *Badly Proportioned Bearings.* — The bearings will heat up if the wearing and bearing surfaces are not suitably proportioned for the work they have to perform. In such cases the bearings will heat at the first run of the machine. The only remedy is to put in new or larger bearings, or an additional one, if the shaft is long enough, and arrangements can be made to admit of this being done.

(*j*) *Bearings out of Line.*—This will be indicated by an unequal wear of the liners, and by the shaft binding or seizing. The remedy is to draw the bolt holes of the bearings until the bearings are correctly aligned with each other and with the armature bore.

(*k*) *Conduction of Heat from Armature.*—The bearings are liable to heat up through the heat developed by an overload or short circuit of the armature, or the production of eddy currents in the core being conducted along the shaft. If due to this cause, the indications and remedies will be as in B (4) (Overload of Dynamo), B (7) (Short Circuits in Armature), C (2) (Heating of Armature, &c.).

D. Excessive Noise or Vibration.—The causes tending to produce excessive noise or vibration in a dynamo are:—

(1.) Bad foundations.
(2.) Loose screws, connections, &c.
(3.) Belt joints.
(4.) Bad adjustment of brushes.
(5.) Knocking of shaft or pulley against bearings.
(6.) Armature out of balance.
(7.) Armature knocking or rubbing against pole pieces.
(8.) Straining of shaft couplings.

D (1.) *Bad Foundations.*—A bad foundation will result in a continuous vibration being set up, and in a greatly increased wear of the commutator and brushes. The foundation should not only be constructed of good and sound materials, but care should be taken that it is carried far enough down to secure a good bottom.

D (2.) *Loose Screws, Connections, &c.*—Examine and screw up tight all screws and bolts liable to slack back.

D (3.) *Belt Joints.*—When the belt is roughly or badly jointed, a noise and vibration is set up as it passes over the pulley. The only remedy is to make a new joint. The efficient working of the dynamo depends in a large measure on the jointing of the belt. Care should therefore be taken in this respect. The belt should be soft and pliable, and the joint should if possible be a long spliced joint, or a butt joint secured with fasteners. A lap joint ought not to be used under any circumstances.

D (4.) *Bad Adjustment of Brushes.*—When this is the case, or when the commutator is in bad condition, or the brushes too hard, a singing or hissing noise is produced at the commutator. The defect may be remedied by adjusting the pressure of the brushes upon the commutator, or by a little lubrication of the latter with vaseline or oil, or by filing or turning down the commutator if in very bad condition.

D (5.) *Knocking of Shaft or Pulley against Bearings.*—This is produced when the shaft has too much end play. To remedy, insert a thin washer or two between the collar of the shaft and the end of the bearing, or between the pulley and the bearing.

D (6.) *Armature out of Balance.*—When this is the case serious vibrations are produced, which vary with the speed of the dynamo. To remedy, the armature should be taken out of the machine, and the journals of the shaft mounted upon two perfectly level knife edges, or, if these are not obtainable, upon two wooden battens fixed edge upwards and very carefully levelled either way. If the armature, when thus mounted, be given a slight motion either way, the heavier side will have a tendency to descend, by which it may be discovered. To balance, it will be necessary to drill a few holes in the heavier side of the pulley, or fix a lead weight upon the inner side of the rim of the pulley on the lighter side.

D (7.) *Armature Knocking or Rubbing against Pole Pieces.*—This may be recognised by the scraping noise produced while the machine is running. It may be caused by the bearings wearing down too far, or through a defective or loose winding. The bearings should first be examined, and if necessary new liners run in or the bearings packed up. If not due to this cause, the armature should be carefully examined to see if any portion of the winding projects, and that it is securely fixed. Any projecting portion of the winding should be carefully beaten down with a mallet, and if necessary new binding wires wound upon the armature to secure the windings in position. If it is found impossible to level down the projecting portion of the winding, the parts of the pole pieces against which it rubs should be filed or chipped away.

D (8.) *Straining of Shaft Couplings.*—When the armature is coupled direct to the engine crank-shaft, and the wear of the bearings is unequal, a straining of the coupling sometimes results which produces a noise. The remedy is to re-line and re-adjust the bearings. In many cases a flexible coupling is provided to prevent this occurring.

E. **Variation or Decrease of Speed.**—This will be indicated by the dynamo failing to excite, or by a decrease of the voltage if the machine is working. The fault may proceed from the undermentioned causes:—

(1.) Reduced speed of driving engine.
(2.) Overload of dynamo.
(3.) Defective bearings.
(4.) Short circuits in armature.
(5.) Armature rubbing against pole pieces.
(6.) Slack or dirty belt.

E (1.) *Reduced Speed of Driving Engine.*—It can readily be ascertained whether the alteration in speed of the dynamo proceeds from this cause by counting the revolutions of the engine with a speed counter. If at any time it is necessary to run an engine driving a shunt or compound dynamo at a lower speed than the normal, the voltage and output of the dynamo can generally be maintained at their ordinary value by coupling up the shunt coils in parallel, thus increasing the strength of the current flowing in the shunt circuit and the strength of the field correspondingly. Care should be taken, however, that the coils do not overheat with the increased current. If this occurs, insert a resistance in series with the shunt circuit.

E (2.) *Overload of Dynamo.*—When the reduction in speed proceeds from this cause, it is accompanied by excessive sparking at the brushes, and heating of the bearings and armature, and slipping of the belt. If the overload be removed as directed in B (4) (Overload of Dynamo), the speed will again attain its normal value.

E (3.) *Defective Bearings.*—When due to this cause, the bearings will be excessively heated, and the shaft will "bind" or "seize," making a noise. It generally proceeds from defective lubrication, and may be remedied as directed in C (4) (Heating of Bearings).

E (4.) *Short Circuits in Armature.*—This practically amounts to an overload of the dynamo, and is accompanied by sparking at the brushes, heating of dynamo, and reduction of speed. The short circuit should be localised, and repaired as directed in Chapter XII. (Faults in Armatures).

E (5.) *Armature Rubbing against Pole Pieces.*—This will result in a diminution of speed if not remedied. The fault may be repaired as directed in D (7).

E (6). *Slack or Dirty Belt.*—If the driving belt is not kept in good order, and free from oil, dirt, &c., a considerable amount of power will be lost in transmission. This will also be the case if the tension of the belt is not properly adjusted. If the motor driving the dynamo is a steam engine, turbine, or other steady running motor, the belt should in all cases be as tight as possible, consistent with the heating of the bearings. In the case of gas or oil engines, however, it will be necessary to have a certain amount of slack on the belt to allow of a little slip on the dynamo pulley, the amount varying with the irregularity of speed of the driving motor.

F. **Variation of Voltage.**—The pressure at the terminals of either shunt, series, or compound dynamos is liable to vary or fluctuate from various causes. In plain shunt or series wound dynamos a variation of pressure under a varying load follows as a consequence to the construction of the machine. A distinction, therefore, needs to be drawn between this natural variation of pressure and an abnormal fluctuation, which also affects compound dynamos, which may occur from time to time in the working of such machines. The causes tending to produce a fluctuation of voltage are:—

(1.) Irregularities of speed.
(2.) Bad joints in belt.
(3.) Short circuits or disconnections in armature circuit.
(4.) Short circuits or disconnections in field magnet circuit.
(5.) Incorrect connections.

F (1.) *Irregularities of Speed.*—Any cause tending to produce a variation in the speed of the dynamo such as is comprised under Section E (Variation of Speed), is responsible for a variation of voltage. Steam engines, turbines, &c., give as a rule very little trouble in regard to irregularities of speed. In the case of gas and oil engines, however, an unsteadiness of speed is always present, owing to their mode of action and construction. Before such motors can be used successfully in driving dynamos, this unsteadiness of speed needs to be reduced and compensated as far as possible. With this object, such engines, when used for driving dynamos, are therefore fitted with extra heavy fly-wheels, and a fly-wheel is also fitted upon the armature spindle of the dynamo. In driving with such engines, the governors and valves are adjusted, if possible, to give an explosion at every revolution of the fly-wheel, and any little irregularity of speed is then compensated by varying the tension and slip of the belt on the dynamo pulley.

F (2.) *Bad Joints in Belt.*—If the belt is not jointed in a suitable manner, it will cause a fluctuation of voltage, and a flickering of the light as the joint passes over the pulley. The belt should in all cases be soft and pliable, and made endless by a long spliced joint, or a butt joint with fasteners, or an endless link belt should be used. Lapped joints should on no account be used.

F (3.) *Short Circuits or Disconnections in Armature Circuit.*—When either of these faults is present, a periodical fluctuation of voltage will be set up, accompanied by sparking at the brushes. When this occurs the machine should be stopped at once, and the fault located, and repaired as directed in Chapter XII. (Faults in Armatures).

F (4.) *Short Circuits or Disconnections in Field Magnet Circuit.*—Either of these faults will give rise to a diminution or increase of voltage. To locate the faults, the entire field circuit should be tested and examined as described in Sections A, B, and C.

F (5.) *Incorrect Connections.*— If on starting a machine for the first time, or after repairs, the voltage is either above or below its normal value, it is possible the variation may be the result of incorrect connections. The whole of the connections, including the armature, brushes, flexible leads, and field coil connections, should therefore be examined and verified.

CHAPTER XII.

FAULTS IN ARMATURES.

THE armature and commutator are the most vulnerable parts of a dynamo, and being subjected whilst rotating to various detrimental influences, are a prolific source of faults, the chiefest of which may be enumerated as follows:—

(1.) Short circuits in armature.
(2.) Grounds in armature.
(3.) Disconnections in armature circuit.
(4.) Flats on commutator.
(5.) Short circuits in commutator.
(6.) Rough and uneven surface of commutator.
(7.) Segments loose or knocked in.

(1.) **Short Circuits in Armatures.**—The classes of short circuits which occur in the armature are—(*a*) Short circuits in individual sections or coils; (*b*) Short circuits between adjacent coils; (*c*) Short circuits between sections through frame or core of armature; (*d*) Short circuits between sections through binding wires; (*e*) Partial short circuits in armature.

(*a*) *Short Circuits in Individual Sections or Coils.*—This is an exceedingly common fault, which makes its presence known by a violent heating of the armature, flashing at the commutator, flickering of the light, and by a smell of burning varnish or overheated insulation. When these indications are present, the machine should be stopped at once, otherwise the armature is liable to be burnt out. The fault is due either to metallic dust lodging in the insulation between adjacent bars of the commutator, or to one or more convolutions of the coils coming into contact with each other, either through a metallic filing becoming embedded in the insulation or damage to the insulation. When the machine is stopped, the faulty coil, if not burnt out, can generally be located by running the fingers over the armature, by its excessive temperature over the rest of the coils, and by the baked appearance of the varnish or insulation. If the machine will not build, and it is suspected that the fault arises from short circuited armature coils, the field magnets should be excited by the current from a storage battery or another dynamo, and having raised the brushes from contact with the commutator, the armature should be run for a short time. In stopping, the faulty coil or coils may be located by the heat generated by the short circuit. When the dynamo is started to localise a short circuit, great precautions should be taken, and the machine only run for a few minutes at a time until the faulty coil is detected. A short circuited coil may also be located by the fall of potential method. Fig. 78 illustrates diagramatically this method of testing. Disconnect the external and field circuits from the armature, and pass a large current —say from 20 to 100 amperes—from a battery (B) or another dynamo through the whole armature by means of the brushes. Then, having previously well cleaned the commutator, measure the difference of potential between adjacent segments all round

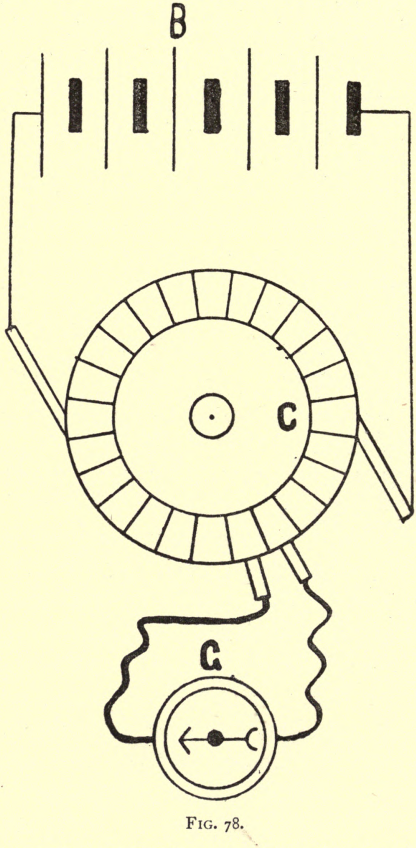

Fig. 78.

the commutator (C), by means of a voltmeter or galvanometer (G), the terminals of which are connected to adjacent segments, as shown. The short circuited coil or coils will be located by the difference of potential between the corresponding segments being little or nothing. It may be remarked, however, that this is not always a decisive test. In some cases the short circuit may be intermittent, or may disappear as soon as the armature ceases to rotate. In such cases, the short circuit is caused by the wire coming into contact through the action of the centrifugal forces developed by the rotation of the armature. The former test is therefore the more reliable in all cases. When the faulty coil has been located, the insulation between the segments of the commutator to which its ends are connected should be carefully examined for anything that may bridge across from plate to plate, and scraped clean from any adherent metallic particles or burrs. If the commutator is apparently all right, the fault probably lies in the winding. The insulation of this should be carefully examined, and any metallic filing or other particle discovered therein carefully removed, and a little shellac varnish applied to the faulty part. It will sometimes happen that a small portion of the insulation has been abraded from two adjacent conductors, thus causing them to come into electrical contact with each other. In such circumstances a small boxwood or other hardwood wedge, coated with shellac varnish, and driven in tightly between the wire, will generally effect a cure. If the faulty coil cannot be expeditiously repaired, and the dynamo is urgently wanted, the coil may be cut out of circuit altogether, and the corresponding commutator segments connected together with a piece of wire, of a size proportionate to the amount of current to be carried, soldered to each. It will not be necessary to cut out and remove the entire coil. If the active portions only are separated from one another, so that they do not for a closed circuit, it will answer the purpose—*e.g.*, if the wires are cut with a chisel at the point where they pass over the ends of the core, and the ends separated, it will be quite as effective as removing the entire coil. It is wise, of course, to rewind the coil at the first opportunity.

(*b*) *Short Circuits between Adjacent Coils.*—Whilst in the ring armature the presence of this fault does not necessarily imply that the machine will not build, in the drum armature wound into a single layer of conductors it entirely prevents this occurring. Reference to Fig. 23 will show that adjacent coils are during a certain period of the revolution at the full difference of potential generated by the machine. Hence, if any two adjacent coils are connected together or short circuited, the whole of the armature will be practically closed on itself, any current generated flowing within the armature only, without passing to the external circuit. Large drum armatures wound with compressed and stranded bars and connectors are particularly susceptible to this fault, a slight blow generally forcing one or more of the strands into contact with the adjacent bars, thus short circuiting the armature, and rendering it practically useless so far as the generation of current is concerned. In this class of short circuit in drum armatures, the method of locating the faulty coils by exciting the field, and running the armatures on open circuit, is not applicable, for the reason that the whole armature will be heated equally. Mr Loomis, in the

Electrical Engineer of New York, has described a method of locating faults of this description, and, as it appears reliable, it is given below. "In following this plan, no arrangement for belting need be made. It is only necessary to fasten a monkey wrench to the rim of the pulley, or, better still, a crank to the shaft. Now, excite the fields, and, to make the effects more marked, connect the coils in parallel, as the excessive current will only be used for a moment. When this has been done the strongest man will scarcely be able to rotate the armature, and then only with extreme slowness, except at one position. When this position has been

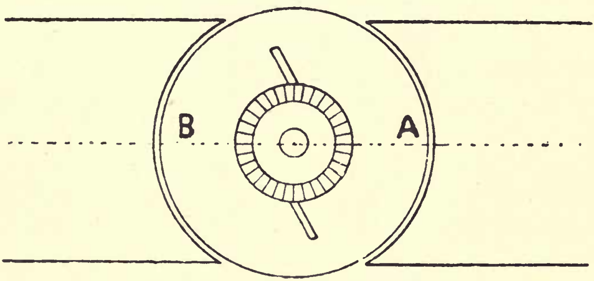

FIG. 79.

found, mark the armature at points in the centre of the pole pieces (A B), as shown in the accompanying diagram (Fig. 79), and at both ends of the armature. The explanation is that both halves of the armature oppose one another at this position; but when not at these points a continuous circuit is formed, and the resultant magnetic effect is enormous. As the "cross" or "short" circuit will be found at one of these four marked points, it becomes desirable to know in which one it is most likely to be found. Experience has shown that it is nearly always on the commutator end in the last half of the winding, where the wires pass down through the first half terminals. This applies to an unequal winding. In armatures where the windings are equal, it is as liable to occur at one point as at another. With this method a defect can be found and remedied in a few moments, for it has always been a simple matter to repair it when discovered. These results can be observed in a perfect armature by connecting the opposite sections of the commutator. The above will be understood to apply to armatures having Siemens winding." Faults of this description can frequently be discovered by a careful inspection of the windings of the armature without recourse to testing. When located, the fault can usually be repaired with a hardwood wedge, as explained above, or a piece of mica or vulcanised fibre cemented in place with shellac varnish.

(*c*) *Short Circuits between Sections through Frame or Core of Armature.*—The localisation of this fault can be effected by the methods described above, and by disconnecting the whole of the armature coils from the commutator and from each other, and testing each separately with a battery and galvanometer coupled up as in Fig. 74, one wire being connected to the shaft and the other to the end of the coil under test. As a rule, there is no way of remedying this fault other than unwinding the defective coils, reinsulating the core, and rewinding new coils.

(*d*) *Short Circuits between Sections through Binding Wires.*—This fault is the result of a loose winding, and is caused by the insulation upon which the binding wires are wound giving way, thus bringing coils at different potentials together. As a consequence to the heavy current which flows, the binding wires are as a rule unsoldered or burned. The location of the fault can therefore be effected by simple inspection. To remedy, it will be necessary to unwind and rewind on new binding wires, on bands of mica or vulcanised fibre, soldering at intervals to obviate flying asunder.

(*e*) *Partial Short Circuits in Armatures.*—This is, as a rule, due to the presence of moisture in the windings. To remedy, the armature should be taken out and exposed to a moderate dry heat, or subjected to a current equal to that ordinarily given by the dynamo. Under the action of heat or of this current the moisture will be gradually dispersed. When thoroughly dry, and whilst still warm, a coat of shellac or rubber varnish should be applied to the whole of the windings.

(2.) **Grounds in Armatures.**

(*a.*) *Armature Coils grounded or connected to Core or Frame of Armature.*—When this fault is confined to a single coil, it is not in itself liable to do any damage. If, however, a similar fault develops in some other part of the dynamo, or in the external circuit, the coil is liable to be burned out. Mr F. Bain, in the *Western Electrician*, has described a simple method of locating a coil grounded to the frame of an armature, which is reprinted below. Fig. 80 clearly shows the arrangements of the details. B is a battery or dynamo circuit, giving a current of a few amperes through the armature by its own brushes (1 and 2). At A, a roughly-made galvanometer, to carry some 25 amperes or so, is placed, one terminal being in connection with the shaft of the armature, and the other attached to a movable brush (3). Since the function of the particular galvanometer is simply to show a deflection when a current is passing, and to mark zero when there is none, a coil of thick wire, with a pocket-compass in the centre, will do all that is required, but care must be taken to remove it sufficiently far away from the disturbing effects of the armature magnetism. The manner of testing is as follows:—Assume a steady current to be flowing

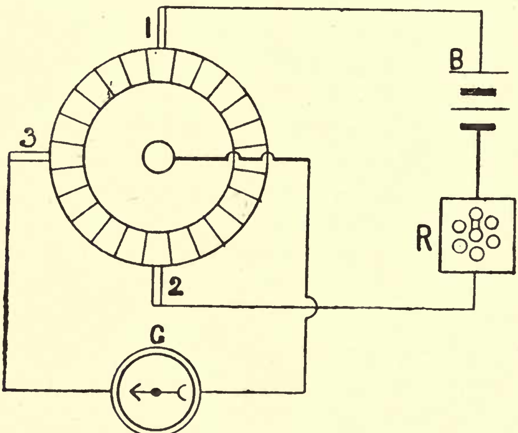

Fig. 80.

from battery (B) through the armature, touch the commutator with brush (3), and a current will flow through (G). Slowly rotate the armature or the brush (3), until the galvanometer (G) shows no deflection. The coil in contact with 3 will be found to be *grounded* or connected to the frame. A hand regulator or rheostat (R) may be inserted in series with the battery or dynamo circuit to regulate the strength of the current passing. The main advantage of this test is that the damaged coil can be located without unsoldering the coils from the commutator, which is sometimes a difficult operation without proper tools; and further, the fault can frequently be repaired without disconnecting any of the wires if its exact position be determined.

(3.) **Disconnections in Armature Circuit.**—A partial or complete disconnection in the armature circuit is always characterised by heavy sparking at the commutator, but not, as a rule, by an excessive heating of the armature or slipping of the belt, and this enables this fault to be distinguished from a short circuit. The faulty part can always be readily located by the "flat" which it produces upon the surface of the commutator. The armature circuit being open at the faulty part, heavy sparking results at every half revolution as the brushes pass over it, and as a consequence the corresponding segments are "pitted" or "flattened" with respect to the others, and may easily be discovered on examination. The fault may occur in either the commutator or in the coils of the armature. To ascertain whether it is in the latter, carefully examine the winding of the faulty coil. The defect may be sought for more particularly at the commutator end of the armature, as breaks in the wire are most frequent where the connections are made with the commutator segments. If no break can be discerned, try passing a heavy current through the faulty coil by means of the brushes. If a disconnection exists in sufficient contact to pass a current, the coil will be heated in the neighbourhood of the disconnection, and may be discovered by running the fingers over the coil. When located, the fault may be repaired by rewinding the coil, or carefully cleaning the broken ends and jointing. The fault may also be temporarily repaired by soldering the adjacent commutator segments together without disconnecting the coil.

(4.) **Flats on Commutator.**—This is the name given to a peculiar fault which develops on one or more bars of the commutator. It is not confined to dynamos of bad design or construction, but frequently appears on those of the highest class, and may be recognised as a "pitting" or "flattening" of one or more segments. It is always accompanied by sparking at the brushes, and may be due to a periodical jumping of the brushes, caused by a bad state of the commutator, or a bad joint in the driving belt, or to a flaw, or a difference in the composition of the metal of the particular bar upon which it appears. But more frequently it may be traced to a more or less developed fault, such as a disconnection, either partial or complete, in the armature coil. The disconnection may occur either in the coil itself, or at the point where its ends make connection with the lug of the commutator, or at the point where the lug is soldered to the segment of the commutator. To remedy the fault, the brushes should be examined to see if any periodical vibration takes place. If such is the case, the cause should be removed, and the flat carefully filed or turned out, and the brushes readjusted. If it is due to a difference in the composition of the metal of which the segment is made, the flat will exist as long as the particular segment is in use, and will need to be periodically turned out if a new segment is not fitted into the commutator. Now that the construction of commutators has been improved, however, by the use of hard-drawn copper or phosphor-bronze segments, this fault is rarely due to this last-mentioned cause. It is more frequently due to bad soldering, or jointing of the conductors to the lugs, or of the lugs to the segments. In all cases of flats, if the disconnection in the armature circuit is not complete, and cannot be readily located, the effect of re-soldering or sweating the ends of the coils into the lugs should be tried. Flats may also frequently be cured by drilling and tapping a small hole in the junction between the lug and the segment, and inserting a small screw, or bit of screwed copper

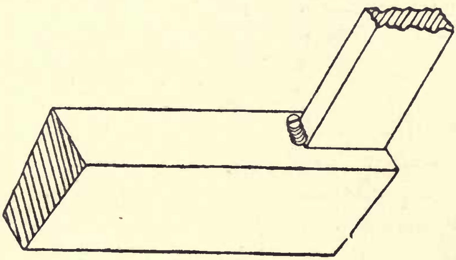

FIG. 81.

or brass wire, as shown in Fig. 81, afterwards filing down level with the surface of the commutator.

(5.) **Short Circuits in Commutator.**—These are of frequent occurrence, and result in heating of the armature and sparking at the brushes. They are caused either by metallic dust or particles lodging in the insulation between the segments, or by the deterioration of the commutator insulation. To remedy, the insulation between the segments should be carefully examined, and any metallic dust, filings, or burrs cleaned or scraped out. When the commutator is insulated with asbestos or pasteboard (as is oftentimes the case in dynamos of continental make), short circuits very frequently occur through the insulation absorbing moisture or oil, which is subsequently carbonised by the sparking at the brushes. In faults of this description the only remedy is to expel all moisture from the commutator insulation by means of heat, and scrape out all metallic dust which may be embedded in the surface of the insulation. If this does not effect a cure, it will be necessary to dig out the insulation, as far as possible, with a sharp tool, and drive in new insulation; oil should not be used on commutators insulated with these materials, but only asbestos dust or French chalk.

(6.) **Rough and Uneven Surface of Commutator.**—This fault is due to bad adjustment of brushes, bad construction of commutator, and to neglect generally. If allowed to continue, it results in heavy sparking at the brushes, and the eventual destruction of the commutator. The fault may be remedied by filing or turning up the commutator in the manner explained in Chapter XI. (Re-Turning Commutator).

(7.) **Segments Loose or Knocked in.**—When the segments are loose, it is an indication that the clamping ring or cone has worked loose. This should therefore be tightened up, and the commutator turned up. When the commutator receives an accidental blow, one or more of the segments is invariably forced below the level of the others. In this condition the commutator is practically useless. To remedy, two courses are open: the commutator surface may be turned down to the level of the knocked-in segment, or the latter may be pulled out again to its former level, this latter being the preferable method, if it can possibly be effected. To pull out the segment, a hand vice is firmly clamped to the lug, or a loop of copper wire is passed round the conductor where it joins on to the commutator. A bar of iron to act as a lever is supported on a fulcrum over the commutator, and one end of the bar is passed through the loop or vice. On pressure being applied to the other end, the knocked-in segment can generally be brought up to its former level. The commutator can then be filed up with a dead smooth file.

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[*Continued on next page.*

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